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# NATIONAL ASSESSMENT OF URBAN RAIL NOISE



Gregory Chisholm
Herbert Bogen
Michael Dinning
Michael Primeggia

U.S. Department of Transportation
Research and Special Programs Administration
Transportation Systems Center
Cambridge, MA 02142

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16. Abstract

This report summarizes seven individual noise assessments of the urban rail transit systems in Boston, New York City, Philadelphia, Lindenwold (N.J.), Cleveland, Chicago, and San Francisco. The assessments were performed by DOT and contractor research teams using a noise measurement methodology developed at TSC and tested on the MBTA in Boston. Sound level measurements were taken inside the transit car, in stations, and in the community situated near the rail rights-of-way.

For the purposes of this national assessment report, measured noise level data have been extrapolated to characterize sound levels at all places on each of the systems. Distributions of noise levels for each transit system are compiled in terms of the acoustic measures $L_A$(Max), $L_{eq}$, and $L_{dn}$. In addition, noise levels in the wayside community (including trains) are compared with estimated ambient community noise levels which would exist if train noise were not present. Finally, estimates are made of the number of persons exposed to the various levels of noise in the transit car, station, and wayside community. Distributions of noise levels and noise exposure are presented for a composite rail system, made up of all seven transit systems.

Several Government and industry noise level guidelines applicable to rail transit systems are discussed. Sound level distributions for each of the seven systems are compared with noise level goals developed by the American Public Transit Association.

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# PREFACE

This report has been prepared as part of the Urban Rail Noise Abatement Program, managed by the Transportation Systems Center (TSC) under the sponsorship of the Office of Rail and Construction Technology, Office of Technology Development and Deployment of the Urban Mass Transportation Administration (UMTA). Dr. Robert Lotz and Dr. Leonard Kurzweil, technical monitors for the study, made important contributions to the report through their guidance and suggestions.

Dr. Herbert L. Bogen, of Raytheon Service Company, provided the framework for the analysis of wayside noise exposure, wrote the section on guidelines for rail noise, and was responsible for the supervision of the Raytheon Service Company staff. Michael Dinning and Michael Primeggia, of Raytheon Service Company, performed much of the analysis of noise levels and exposure as co-investigators with Gregory Chisholm, and made substantial contributions to the methodology of the analysis of wayside noise exposure, as well as writing the major portion of the final report.

Helpful advice was provided by Professor John Large, of the Institute of Sound and Vibration Research, Southhampton, U.K., while consulting at the Transportation Systems Center. Assistance was also provided by Jeffrey Benjamin, Scott Crout, Nancy Cooney, James Sterling, Adelle Ransom, and John Verrilli, of Raytheon Service Company.

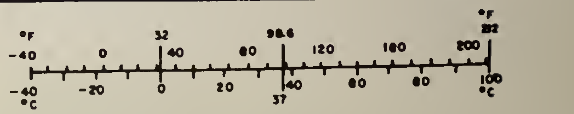
# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |


## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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## BACKGROUND

### Role of the National Assessment of Urban Rail Noise

This report presents a national assessment of noise generated by urban rail transit vehicles as it is experienced by riders in transit cars, patrons on station platforms, and nearby community residents.

The National Assessment report was produced as a part of the Urban Rail Noise Abatement Program administered for the Urban Mass Transportation Administration by the U.S. Department of Transportation, Transportation Systems Center (TSC). This program is directed towards the reduction of urban rail noise through the introduction of improved urban rail technology and the more effective use of available technology.

The National Assessment report provides an overview of the urban rail noise problem and its distribution among U.S. transit systems, and should prove useful for the following purposes:

1) Assessing environmental impacts of rail transit noise.
2) Evaluating impacts of improvements resulting from the application of noise abatement techniques.
3) Assisting decision-making regarding the distribution of noise control capital assistance.
4) Establishing guidelines or equipment specifications with regard to urban rail noise levels.

### Assessment Scope

The National Assessment assimilates the results of individual assessments performed by separate contractors on the urban rail systems operated by:

1) Massachusetts Bay Transportation Authority (MBTA), Boston, MA.

2) Southeastern Pennsylvania Transportation Authority (SEPTA), Philadelphia, PA.
3) Port Authority Transit Corporation (PATCO), Philadelphia to Lindenwold, NJ.
4) Greater Cleveland Regional Transit Authority (RTA), formerly the Cleveland Transit System (CTS).
5) Bay Area Rapid Transit District (BART), San Francisco, CA.
6) Chicago Transit Authority (CTA).
7) New York City Transit Authority (NYCTA), including the Staten Island Rapid Transit Operating Authority (SIRTOA).

These eight systems include the following: 491 miles (786 km) of right-of-way, 50 percent of which are on the two New York systems; 785 stations, 62 percent of which are in New York; and 9370 rail transit vehicles in operation, 70 percent being in the two New York systems. [The Washington Metropolitan Area Transportation Authority (WMATA) had not begun urban rail operations at the time the noise measurements were made.]

## Summary of Methodology

For the purposes of this National Assessment report, measured noise level data have been extrapolated to characterize sound levels at all places on each of the transit systems. Distributions of noise levels for each transit system are compiled in terms of the maximum sound levels, $L_A$(Max), and the equivalent sound levels, $L_{eq}$ or $L_{dn}$. In addition, noise levels in the wayside community (including trains) are compared with estimated ambient community noise levels which would exist if train noise were not present. Finally estimates are made of the number of persons exposed to the various levels of noise in the transit car, station, and wayside community.

## PRINCIPAL FINDINGS

### Determinants of Urban Rail Noise

The patterns of noise levels which emerge from the National Assessment confirm many of the findings of other researchers concerning the sources and propagation of urban rail noise. The primary determinant of noise levels for a given train is the type of track structure on which the train is running. In-car and in-station noise levels are highest in underground sections. Sound levels in the wayside community are greatest along elevated track structures, steel structures being typically noisier than concrete structures. Also related to higher noise levels are greater train speeds, the presence of jointed rail (as opposed to welded), particular track geometry configurations such as curves, and adverse wheel and rail conditions such as wheel flats and rail corrugations.

The application of noise abatement technology has had significant results on some of the transit systems studied. Acoustical treatment in underground stations on BART has resulted in sound levels which are lower than the levels in the system's aerial stations. In the case of the MBTA and NYCTA systems, sound levels inside transit cars built with acoustical considerations are on the order of 5 to 15 dBA less than levels in non-acoustically treated cars.

### National Distributions of Noise Levels and Noise Exposure

The results of the National Assessment analyses have been summarized in aggregate distributions of noise levels and noise exposure. Because of the size of the New York systems, data from these two systems have been presented separately. The data from the remaining six systems have been combined into a composite system.

## Maximum Noise Levels

Figures 1, 2, and 3 present distributions of maximum sound levels, $L_A(\text{Max})$*, experienced in the transit car, station, and wayside community, respectively.

The highest in-car $L_A(\text{Max})$ levels are typically in older transit cars on underground route segments, which are most prevalent on SEPTA, NYCTA, and CTA.

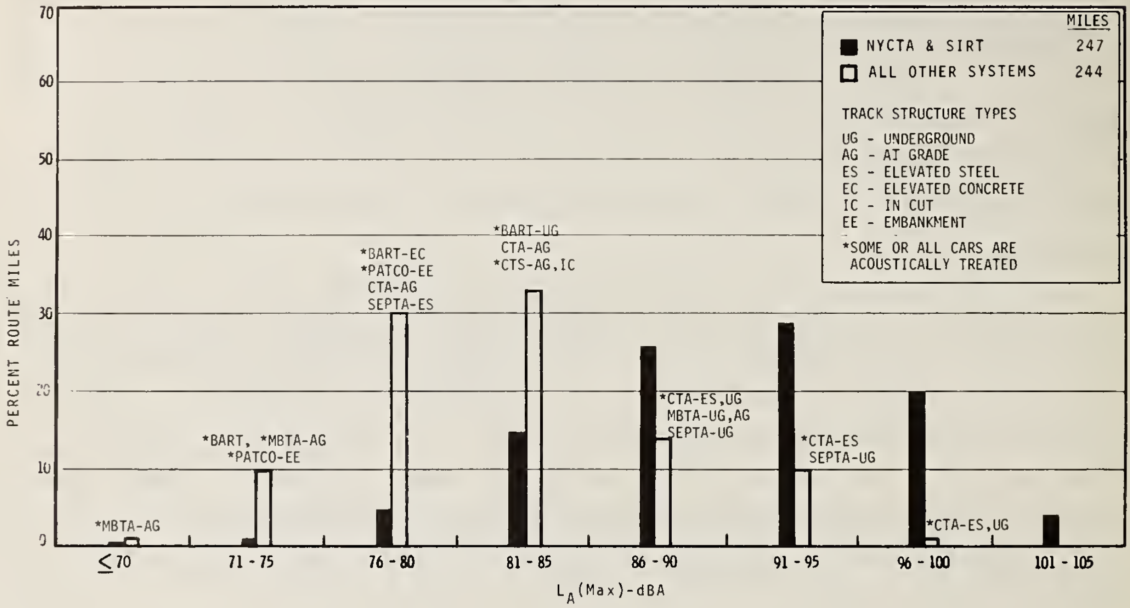


FIGURE 1. MAXIMUM IN-CAR NOISE LEVELS

*$L_A(\text{Max})$ is the maximum sound level experienced by a person during the period of exposure.

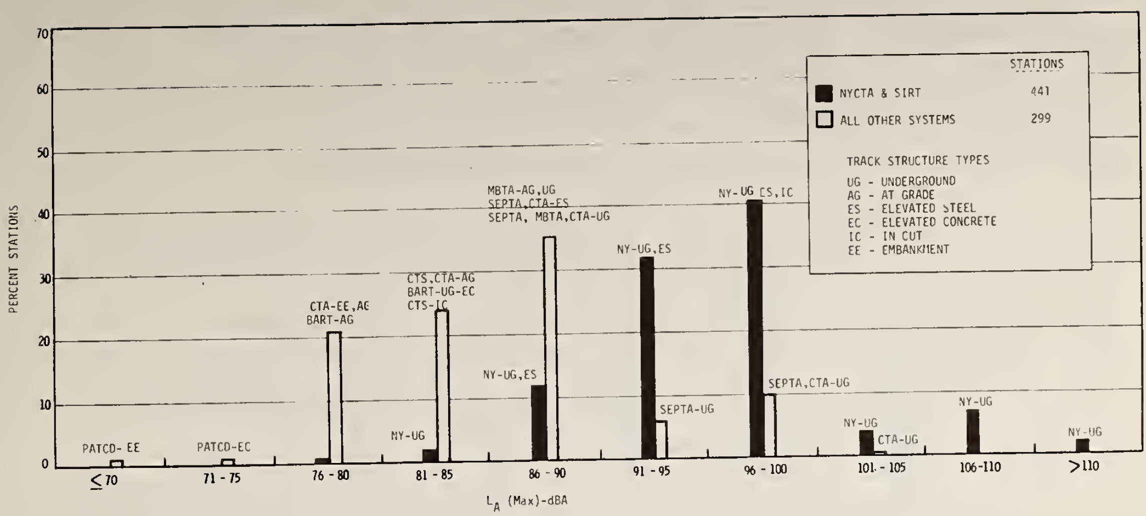


FIGURE 2. MAXIMUM IN-STATION NOISE LEVELS

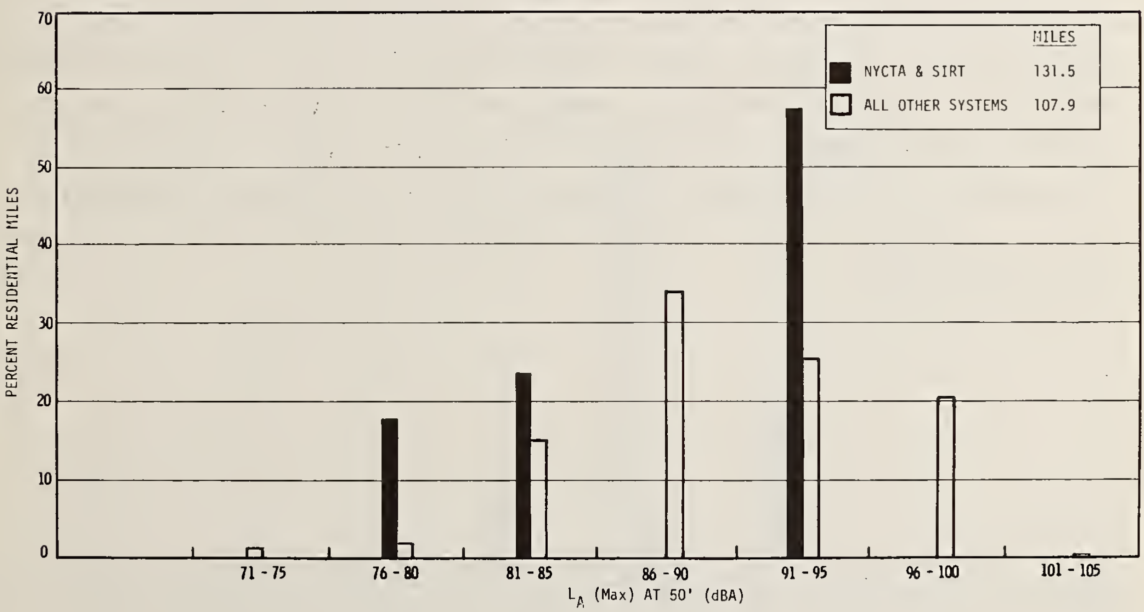


FIGURE 3. MAXIMUM WAYSIDE PASS-BY NOISE LEVELS

## Noise Exposure

Figures 4, 5, and 6 present estimates of the proportions of patrons and wayside community residents exposed to each "average" level of noise ($L_{eq}$ or $L_{dn}$*) in the transit car, station, and wayside community. The wayside sound levels are expressed relative to the ambient community sound levels excluding train noise. (Because of the large size of the NYCTA, exposure assessments were made for only two lines, the IND-D and the IRT-#5.)

Distributions of exposure depend on the geographic distribution of patronage and residential wayside areas throughout the systems, as well as the respective noise levels. For example, in Figure 5, the concentration of in-station exposure on the two New York lines in the 86 to 90 dBA interval reflects heavy patronage in underground stations in Manhattan.

The interpretation of the distribution of wayside exposure is more ambiguous, however, because the magnitude of the relative $L_{dn}$ level characterizing each wayside community area depends on the ambient community noise levels, as well as the noise due to train pass-bys. For example, as shown in Figure 6, the distribution of wayside noise exposure for the two New York lines is characterized by lower relative noise levels than for much of the composite system, because the ambient community noise levels which would exist without train pass-bys are relatively high. In contrast, relative $L_{dn}$ levels along elevated steel track of the composite system are much higher because ambient community noise levels are relatively low.

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*$L_{eq}$, the Equivalent Sound Level, represents the equivalent steady noise level which in a given period of time would contain the same noise energy as the time-varying noise during the same period. $L_{dn}$, the Day-Night Equivalent Sound Level, is similar to $L_{eq}$, but with a penalty applied to sound events which occur during nighttime hours (2200-0700).

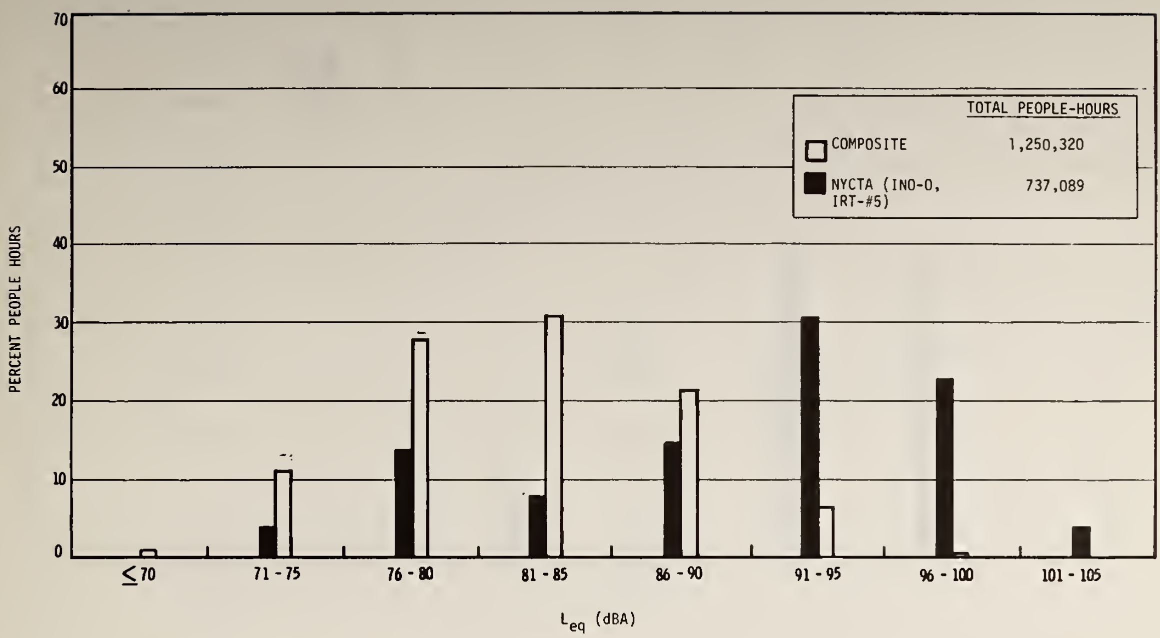



FIGURE 4. IN-CAR NOISE EXPOSURE

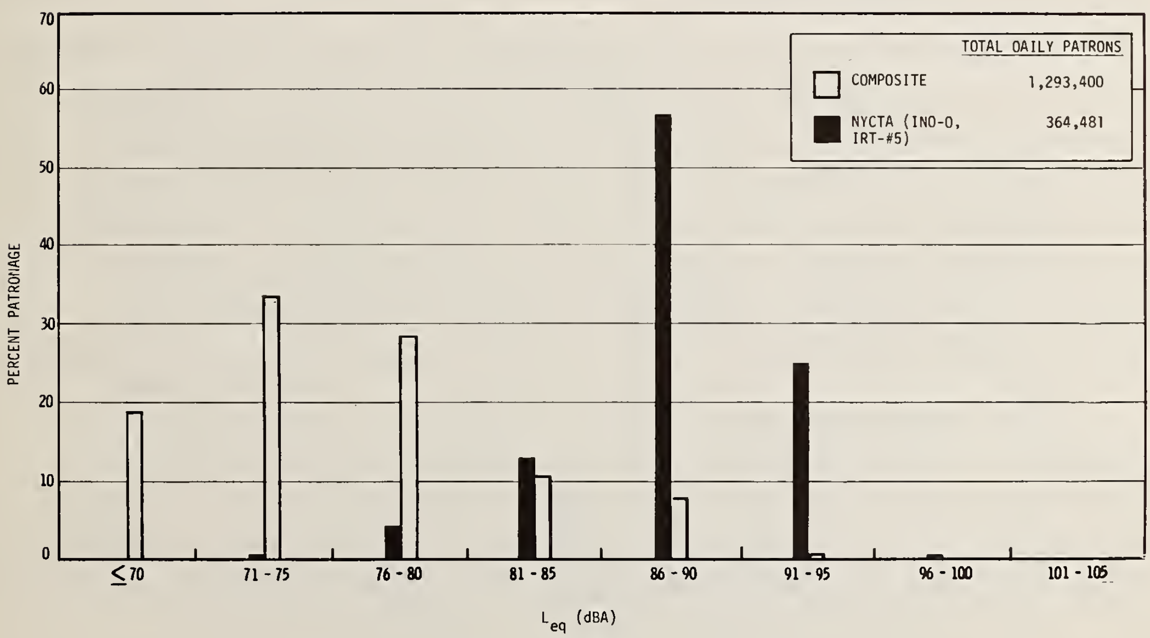



FIGURE 5. IN-STATION NOISE EXPOSURE

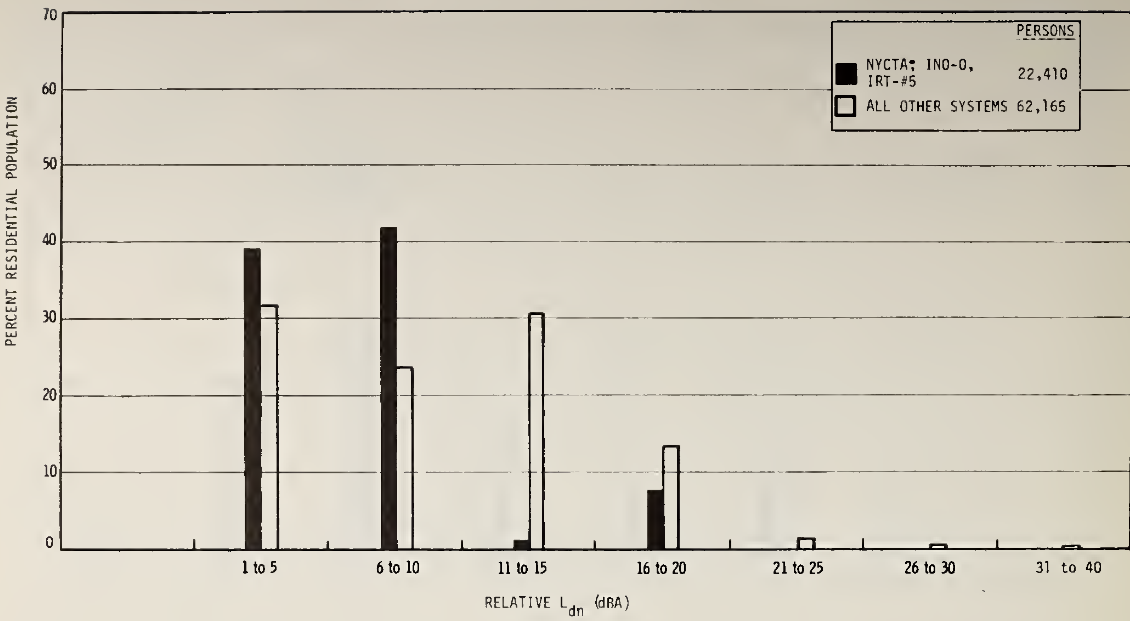



FIGURE 6. WAYSIDE NOISE EXPOSURE

## National Assessment Summary

Average noise levels and estimates of exposure for the in-car, in-station, and wayside environments of each transit system are presented in Table 1. System-wide average maximum in-car and in-station levels are generally lowest in the newer systems with acoustically treated cars or stations. There is a less distinct pattern among systems with regard to average maximum pass-by levels in the wayside community; wayside $L_A$(Max) levels are quite variable with regard to train speed and wheel-rail conditions.

The equivalent sound levels, $L_{eq}$ and $L_{dn}$, are related, of course, to the maximum sound levels, but also account for the cumulative duration of the noise events, and hence are sensitive to variations in system operating characteristics (i.e., train speed and frequency of operations). The magnitude of the wayside

## TABLE 1. SUMMARY - NATIONAL URBAN RAIL NOISE ASSESSMENT

| | MBTA (Boston) | SEPTA (Philadelphia) | PATCO (New Jersey) | RTA (Cleveland) | BART (San Francisco) | CTA (Chicago) | NYCTA-2LINES (New York) |
|---|---|---|---|---|---|---|---|
| Route Length (ROW Miles) | 34.9 | 23.7 | 14.2 | 19.0 | 70.4 | 86.3 | 45.6 |
| Average Daily Ridership | 234,000 | 337,100 | 39,500 | 37,100 | 118,800 | 527,350 | 364,500 |
| Wayside Population Within 200 Feet | 5,750 | 5,500 | 2,000 | 2,800 | 9,800 | 36,250 | 22,400 |
| IN-CAR NOISE | | | | | | | |
| Average Inter-Station $L_A$(Max)-dBA | 82 | 85 | 76 | 83 | 80 | 85 | 90 |
| (Standard Deviation)-dBA | (6.1) | (5.9) | (3.2) | (1.5) | (3.3) | (3.7) | (4.2) |
| $L_{eq}$(R)-dBA* | 79 | 84 | 73 | 81 | 78 | 84 | 89 |
| IN-STATION NOISE | | | | | | | |
| Average Station $L_A$(Max)-dBA | 87 | 92 | 80 | 82 | 80 | 85 | 100 |
| (Range)-dBA | (80-93) | (80-98) | (70-89) | (77-88) | (76-85) | (75-103) | (83-112) |
| Average Station $L_{eq}$-dBA | 76 | 80 | 72 | 73 | 69 | 75 | 87 |
| WAYSIDE NOISE | | | | | | | |
| Average $L_A$(Max) in Residential Areas at 50 Feet-dBA | 87 | 86 | 84 | 95 | 89 | 92 | 87 |
| (Range)-dBA | (83-92) | (76-89) | (76-94) | (84-99) | (86-91) | (74-101) | (76-102) |
| Average Relative $L_{dn}$-dBA | 9 | 8 | 6 | 12 | 9 | 11 | 7 |

*Average in-car $L_{eq}$ level for entire system.

exposure measure relative $L_{dn}$ is particularly system-specific, as it varies also with wayside community ambient sound levels.

Guidelines for Urban Rail Noise

As part of the National Assessment, maximum noise levels on the eight transit systems have been compared with the noise level guidelines established by the American Public Transit Association (APTA). These guidelines represent the transit industry's own view of what is desirable and practicable in the control of rail transit noise. The guidelines are based on speech privacy and passenger comfort criteria. The guidelines, which are in terms of maximum sound levels, $L_A$(Max), specify in-car noise level goals ranging from 70 to 80 dBA and in-station goals from 75 to 85 dBA, varying according to the type of track structure in use. Guidelines for the noise levels in the wayside community vary according to the type of buildings and land use in the wayside community. These goals range from 70 dBA for noise sensitive residential areas to 85 dBA for industrial areas.

In-car noise levels exceed the APTA goals for approximately 90 percent of the total route mileage of the eight systems. Maximum sound levels meet the APTA goals in only about seven percent of the rail transit stations. At the time of measurement, maximum noise levels in all stations in New York exceeded the APTA goals.

The APTA guideline criteria have been compared with noise level criteria proposed by the Environmental Protection Agency (EPA) and the Federal Highway Administration (FHWA). The EPA criteria are intended to provide for normal outdoor speech communication and also to protect against sleep interference and hearing damage. In terms of day-night equivalent levels, $L_{dn}$, the criterion for residential areas established by the EPA is the most stringent (55 dBA), as opposed to APTA and FHWA criteria of 63 and 71 dBA,* respectively.

*Computed based on APTA/FHWA goals in terms of $L_A(\mathrm{Max})/L_{eq}$, assuming the frequency of train pass-bys, train lengths, and train speeds to be similar to those on the MBTA Red Line.

# 1. INTRODUCTION

This report presents a national assessment of noise generated by urban rail transit vehicles as it is experienced by riders in transit cars, patrons on station platforms, and nearby community residents.

The work was done as part of the U.S. DOT Transportation Systems Center (TSC) Urban Rail Noise Abatement Program, sponsored by the Urban Mass Transportation Administration (UMTA), Office of Technology Development and Deployment, Office of Rail and Construction Technology. The National Assessment is the first stage of the TSC Noise Abatement Program, which is directed towards the reduction of urban rail noise and hence improvement of the urban environment through the introduction of improved technology and more effective use of available technology for noise abatement in urban rail systems.

The basic goal of the National Assessment effort is to provide an overview of the urban rail noise problem and its distribution among U.S. transit systems. To obtain the baseline information required to achieve this goal, TSC developed an urban rail noise assessment methodology, which was tested on the Massachusetts Bay Transportation Authority (MBTA) rail lines in Boston. This methodology was refined and applied on the Bay Area Rapid Transit System (BART) by Wilson, Ihrig and Associates, and on the Southeastern Pennsylvania Transportation Authority (SEPTA), the Port Authority Transit Corporation (PATCO), and the Regional Transit Authority (RTA) (formerly the Cleveland Transit System) by the Boeing Vertol Company. Sponsored by grants from the UMTA Office of University Research and Training, similar assessments were made of the Chicago Transit Authority (CTA) by the University of Illinois at Chicago Circle, and the New York City Transit Authority (NYCTA) and the Staten Island Rapid Transit (SIRT) by the Polytechnic Institute of New York.

This report consolidates the results of the individual assessments of each of the seven transit systems (SIRT is

summarized as part of the NYCTA assessment report). In addition, noise level data have been related to patronage and wayside community information to give estimates of national noise exposure in each rail environment. The objectives in assimilating this information into a national assessment are:

1. To present the data obtained from the assesement of individual systems in a manageable format.

2. To provide an approach for comparing the noise levels and noise exposure of different systems.

3. To provide characterizations of all systems which, when aggregated, provide a basis for national policymaking.

The results are useful for a) assessing the environmental impacts of rail transit noise; b) evaluating the impacts of improvements resulting from any proposed regulation of noise emissions and/or application of noise abatement techniques; c) assisting decision makers regarding the distribution of noise control capital assistance; and d) establishing guidelines or equipment specifications with regard to urban rail noise levels.

Section 2 gives an overview of the noise problem by describing rail transit noise sources, paths, and receivers. Also explained are the terminology used in this report and the methods used to assess noise exposure.

Section 3 presents a summary of Government and industry guidelines for noise levels applicable to future and existing transit systems.

Section 4 summarizes the results of the noise measurement analyses. This is done by postulating a Composite Rail System, which includes track structures and vehicles of the types found in the systems studied, and in the same proportions.

Section 5 includes a table summarizing the range and mean of noise levels in each receiver environment for each of the seven systems. Recommendations for more detailed assessments of rail transit noise levels and amount of exposure are also included.

Detailed individual descriptions of the seven transit properties and their noise environments are included as Appendices A through G. Technical Appendices H, I, and J describe the analytical methods used to apply and supplement measured noise data.

# 2. APPROACH AND METHODOLOGY

## 2.1 DETERMINANTS OF URBAN RAIL NOISE

### 2.1.1 Receivers, Sources, and Paths of Noise

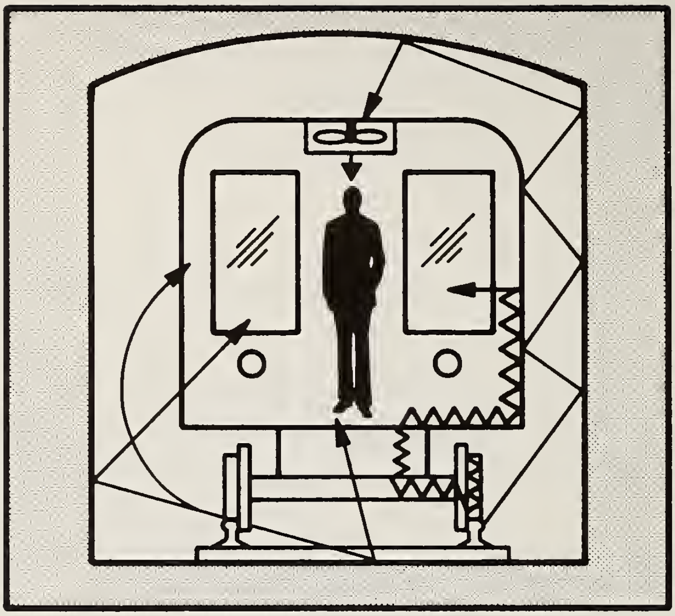
Urban rail noise has been categorized in this report by the location of the receivers of this noise; that is, in-car noise experienced by riding passengers and crew; in-station noise heard by employees and waiting passengers; and wayside noise experienced in the communities situated near the rail right-of-way. The noise experienced by receivers in each category may originate from several different sources, travelling via various paths to reach the receiver.

For most rail rapid transit systems the primary sources of noise are wheel-rail interaction and the train propulsion system. Wheel-rail noise is generated by several mechanisms. "Roar" noise is produced by rolling contact between rough wheel and rail surfaces. Impact noise, consisting of short-duration sounds, is produced by flat spots on wheels striking the rail, and by wheels running over discontinuities in the rail surface, such as rail joints and switches. Finally, wheel "squeal" is generated by wheels sliding on the rail, ususally on sections of curved track.

Whatever the combination of phenomena, wheel-rail noise is radiated directly from the wheels and rails, and, secondarily, from vibrating structural elements, such as the rail supports and the transit car body.

### 2.1.2 In-Car Noise

Figure 2-1 illustrates the predominant paths noise follows to reach the occupants of transit cars. Noise from wheel-rail interaction and the propulsion system travels via airborne paths directly through "leaks" in the car shell. When the car is travelling on underground track, airborne sound is reflected off the subway tunnel walls, creating a reverberant field of sound. This results in higher in-car sound levels in subways than along the aboveground track. In addition, structure-borne vibration is transmitted



SOURCES:

- WHEEL-RAIL INTERACTION
- PROPULSION SYSTEM
- IN-CAR AUXILIARIES

PATHS:

AIRBORNE

STRUCTURE-BORNE VIBRATION

FIGURE 2-1 IN-CAR NOISE SOURCES AND PATHS

from wheels, motors, and under-car equipment to interior surfaces which then radiate noise inside the car. Finally, some sound may be transmitted via airborne paths from sources within the car itself, such as ventilation equipment.

The primary determinant of in-car noise is the type of construction used in the transit car. Newer cars with acoustical treatment such as a high transmission loss body and good vibration insulation will have lower in-car sound levels than older, uninsulated cars.

### 2.1.3 In-Station Noise

Predominant sources of noise experienced by persons in a transit station during train arrival, departure, or pass-through include wheel-rail interaction, mechanical brakes, impulsive air release from the brake system, door operation, air conditioning, and train auxiliary equipment.

As illustrated in Figure 2-2, in-station noise follows direct airborne paths, is reflected off station walls and ceilings and, to a lesser extent, is radiated from vibrating guideway and station surfaces. Station and tunnel entrance size and configuration (number of platforms, barrier and tunnel dimensions) and the amount of sound absorption in a station all affect the propagation and duration of station noise.

The highest noise levels occur where older cars run non-stop on jointed rail through underground stations without sound-absorptive treatment. Local operations (i.e., all trains stop at the station), modern cars with trued wheels, welded rail, modern underground station design with noise control features all contribute to a reduction in noise level. The quietest stations are aboveground, have tie and ballast track, and are protected from background noise from other sources, such as highways.

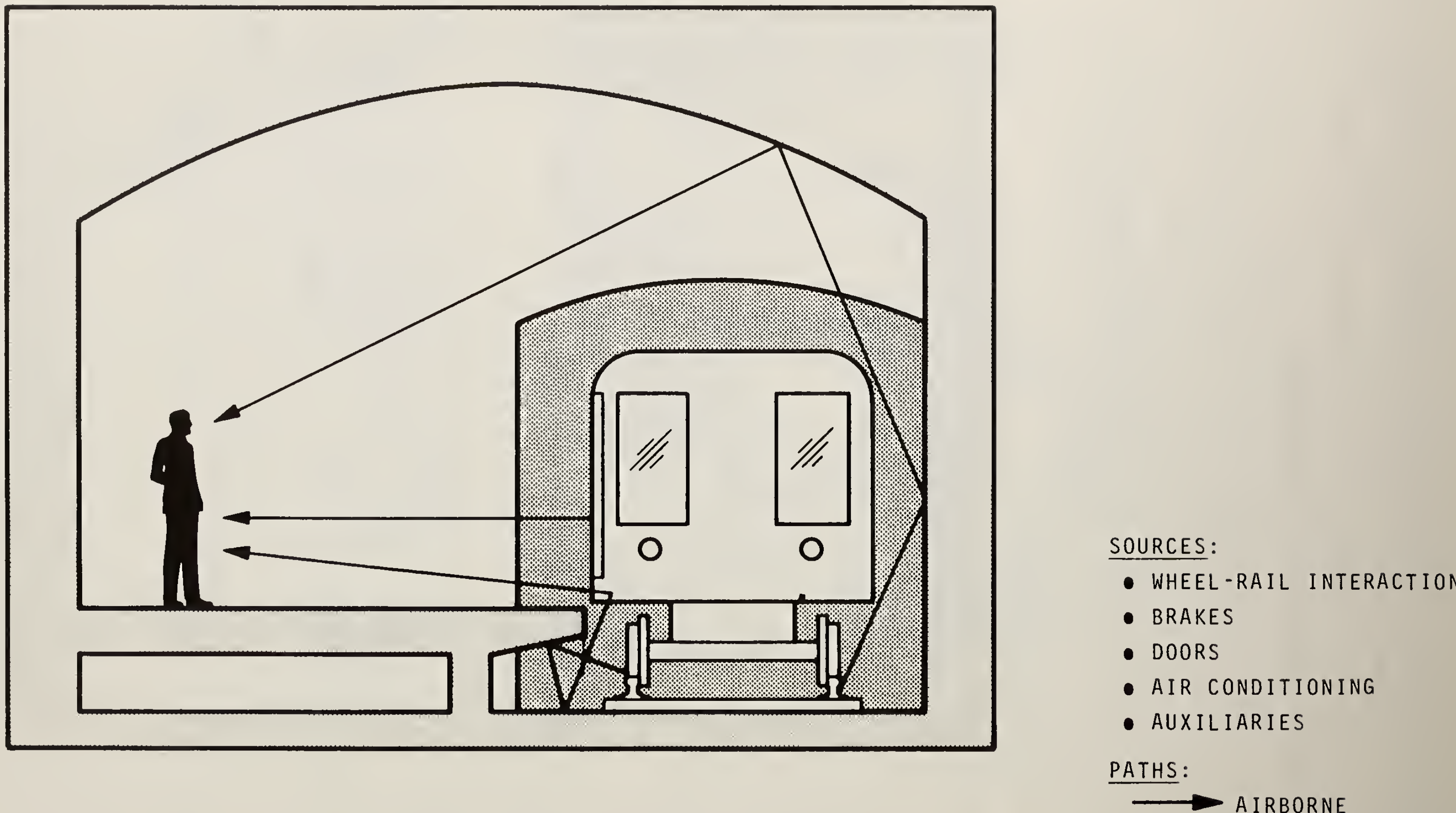



FIGURE 2-2 IN-STATION NOISE SOURCES AND PATHS

### 2.1.4 Wayside Noise

Train pass-by noise from wheel-rail interaction and the propulsion system is transmitted to the wayside community primarily by direct airborne paths from the rails and under-car area, as shown in Figure 2-3. In addition, wheel-rail interaction by trains travelling on elevated track creates vibration in the elevated structure which then radiates additional noise to the wayside community. This noise may exceed that from the direct airborne paths.

The type of track construction is also a major determinant of wayside sound levels, with wheels on jointed rail producing higher wayside sound levels than wheels on continuous welded rail.

For pass-bys on similar type of track structures and similar track construction, higher train speeds will result in higher sound levels in the wayside community as well as in stations and in transit cars.

Wayside sound levels are a function of receiver location, as the intensity of sound decreases with increasing distance from the track. Figure 2-4 illustrates the change in sound level by distance for trains of various lengths.

Vehicle type appears to have relatively little bearing on wayside sound levels. More important are car conditions, particularly conditions of trucks, propulsion systems, and wheels. Car conditions generally get worse as a car ages. In addition, some car types appear more prone than others to particular noise-generating conditions, such as wheel flats.

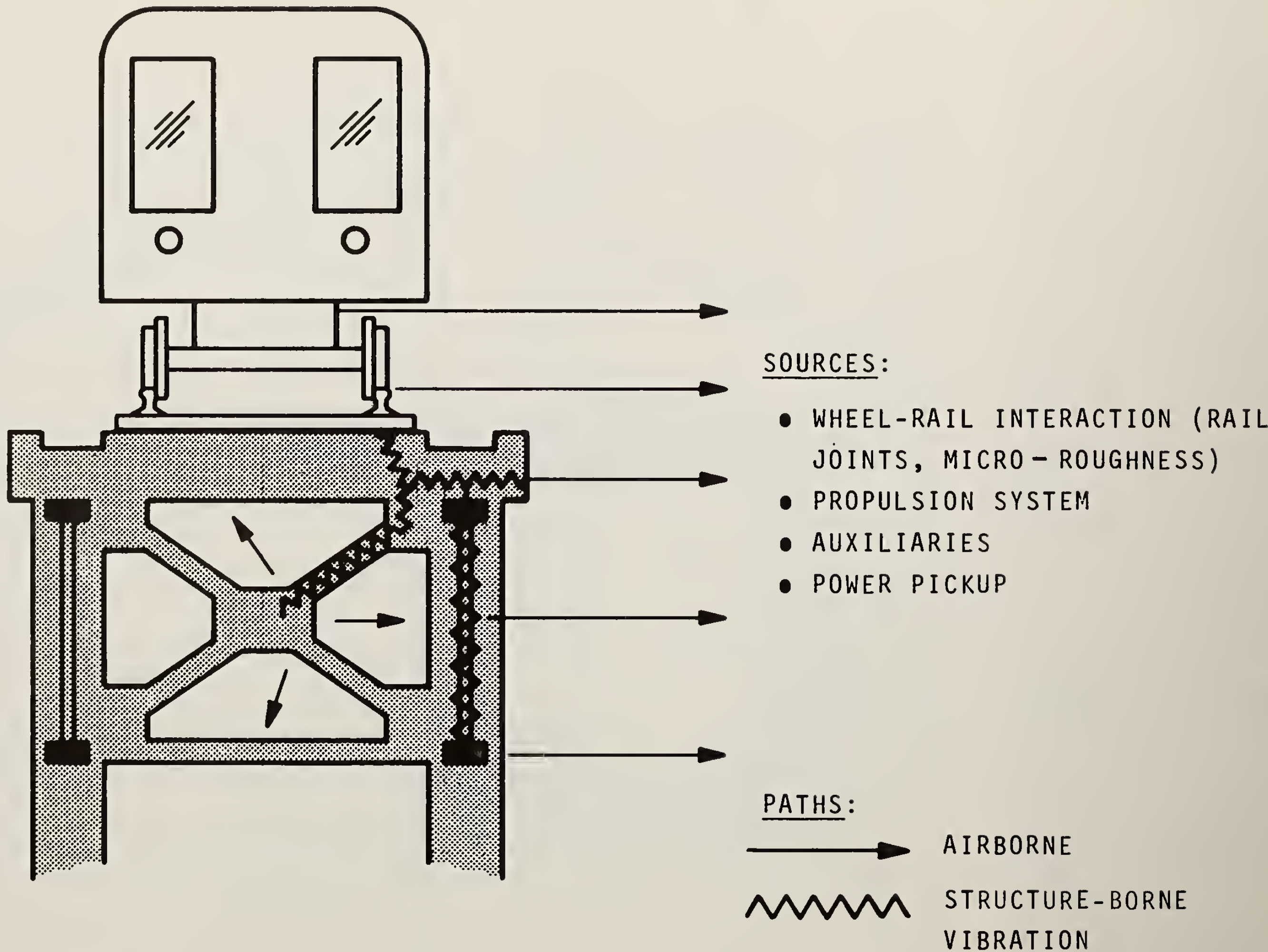



FIGURE 2-3 WAYSIDE NOISE SOURCES AND PATHS

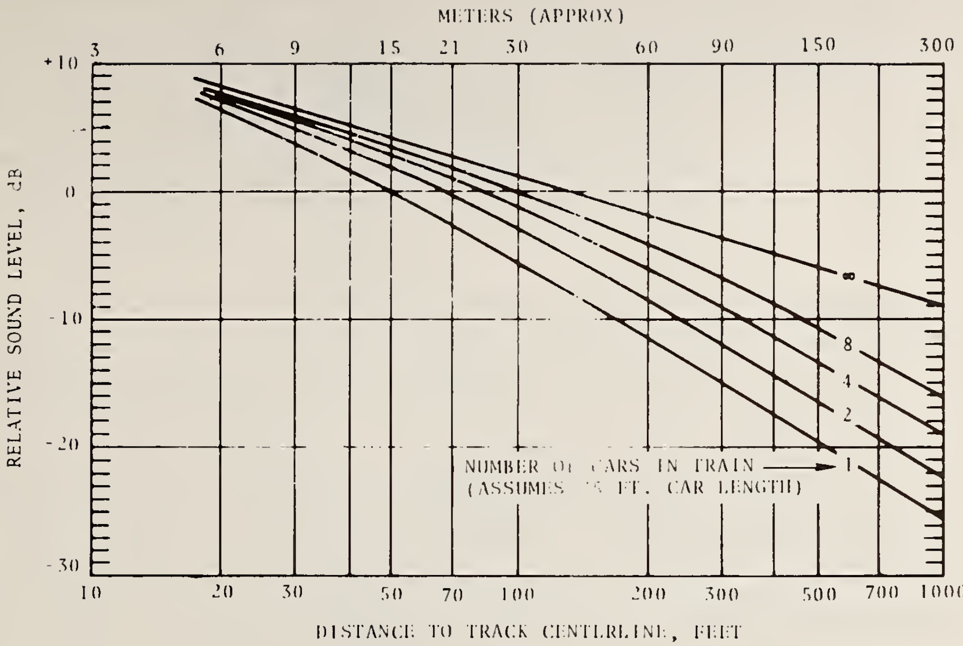



FIGURE 2-4 CHANGE IN SOUND LEVEL WITH DISTANCE FROM THE TRACK RELATIVE TO A ONE-CAR TRAIN AT 50 FEET

## 2.2 DEFINITIONS OF NOISE MEASURES

Several measures of sound levels and noise exposure are used in this report to characterize the noise environments of U.S. urban rail systems. These measures are defined briefly below*; more detailed discussions are contained in Appendices H-J.

Sound (or Noise) Level: This report expresses sound levels in terms of A-weighted decibels (dBA). The decibel scale measures the relative noisiness of sounds, and the A-weighted decibel scale weights middle frequency sounds more heavily, similar to the weighting applied by the human ear. An increase of 10 dBA in the sound level is perceived as a doubling in the loudness of a noise. In this report, the terms sound level and noise level are used interchangeably, and both refer to the A-weighted sound pressure level.

Maximum A-Weighted Sound Level, $L_A$(Max): This is the maximum A-weighted sound level experienced by a person during the period of exposure.

A sample sound level pattern inside a transit car is shown in Figure 2-5. In this report the $L_A$(Max) represents the sustained plateau level which generally occurs as the train reaches top speed. Variations in in-car noise level patterns, and the in-car measurement methodology are discussed in Appendix H.

A time history typifying noise levels experienced by patrons waiting in a transit station is shown in Figure 2-6. Entering and departing trains (and pass-throughs when present) generally produce the maximum sound levels in a station.

Figure 2-7 represents the sound levels experienced by a receiver in the wayside community during train pass-bys. The model of sound attenuation with distance, shown in Figure 2-4, has been used to normalize wayside sound measurements to what they would be at 15 meters (50 feet) from the near track center-line. Levels

*All of the measures are given in dBA's.

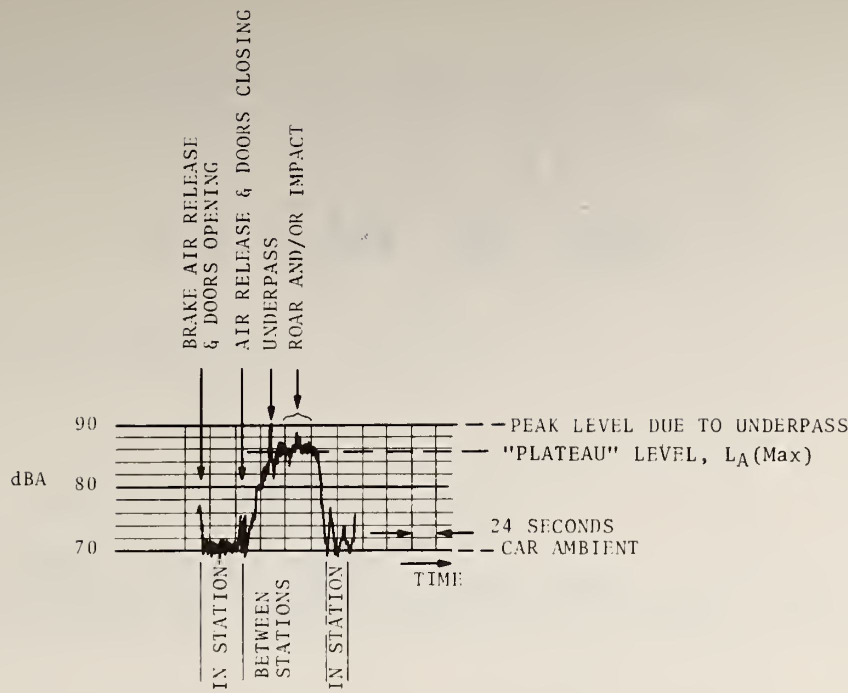



FIGURE 2-5 SAMPLE TIME HISTORY OF IN-CAR NOISE LEVELS

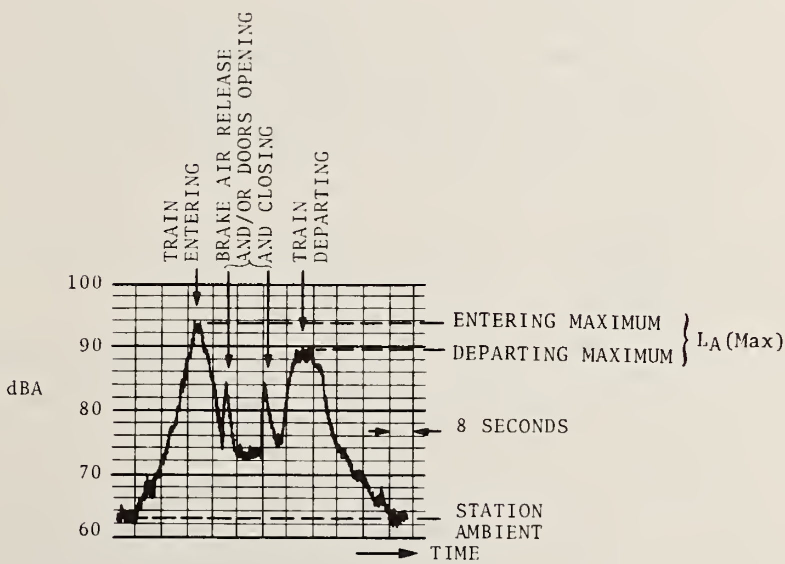



FIGURE 2-6 SAMPLE TIME HISTORY OF STATION PLATFORM NOISE LEVELS (dBA)

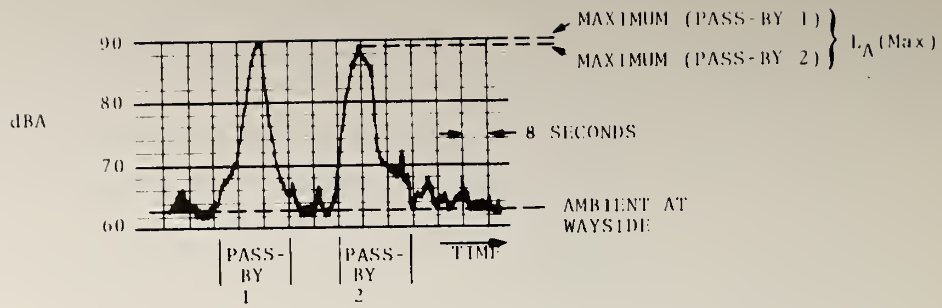


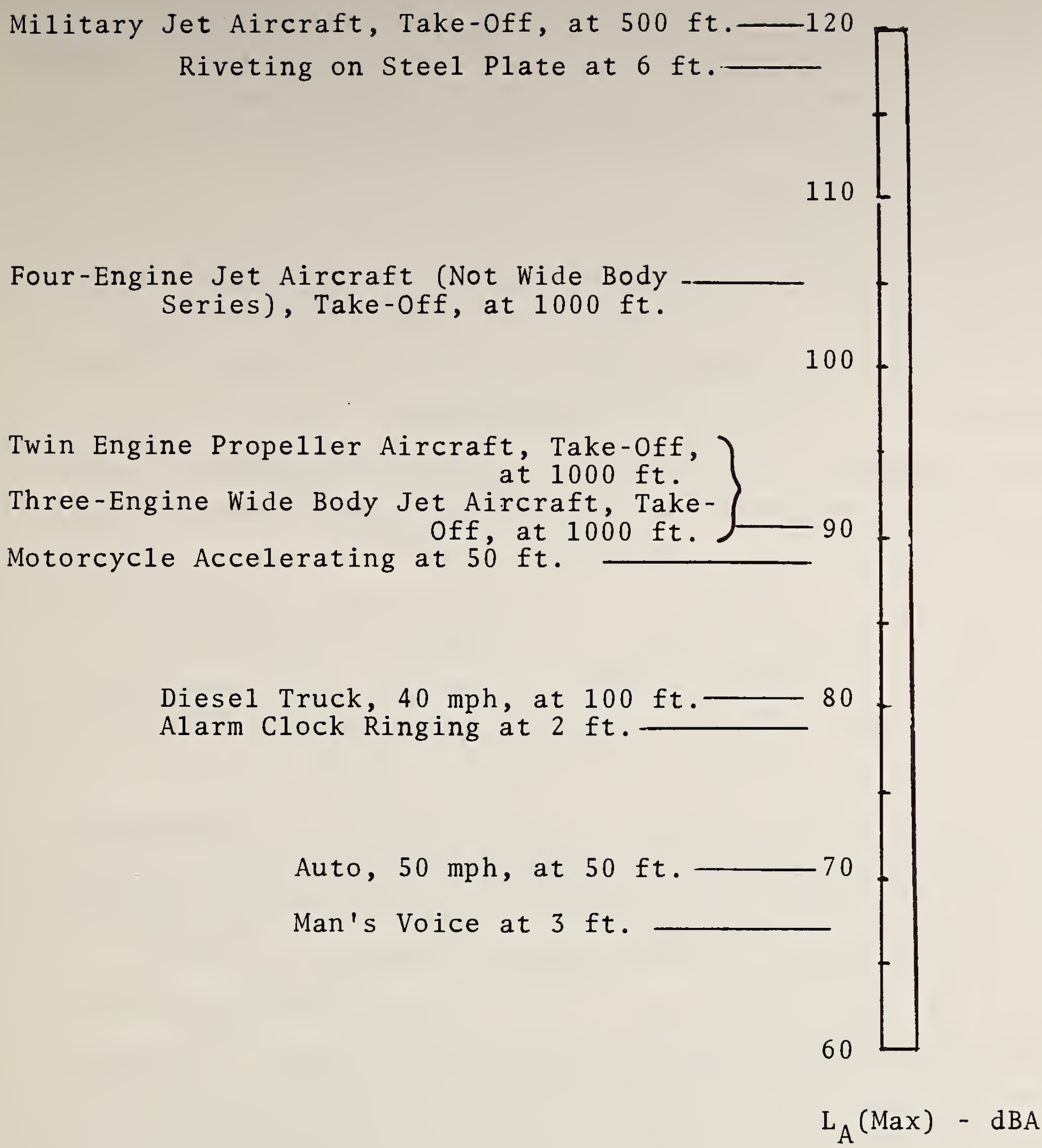

FIGURE 2-7 SAMPLE TIME HISTORY OF WAYSIDE NOISE LEVELS (dBA) FOR TWO 4-CAR TRAIN PASS-BYS IN SUCCESSION

at 50 feet have been used in this report in making intersystem comparisons of wayside $L_A$(Max).

Although measurements of in-car noise were made for the entire route, wayside and station measurements were usually taken at only a few sites. In order to make extrapolations based on measured noise levels, the assumption was made that stations and sections of track having similar types of track structure and served by similar transit cars would have the same noise levels.

Typical $L_A$(Max) levels for sources other than rail transit vehicles are compared in Figure 2-8.

Equivalent Sound Level, $L_{eq}$: While the measurement of $L_A$(Max) is useful in assessing the maximum noise level produced by single events or passages, a measure representative of the cumulative effect of many events over a period of time may be more appropriate in assessing the impact on train passengers or wayside communities. The Equivalent Sound Level, $L_{eq}$, is such a measure, representing the equivalent steady noise level which in a given period of time




Source: U.S. EPA, "Report to the President and Congress on Noise," and U.S. DOT, "Transportation Noise and Its Control."

FIGURE 2-8 COMPARISON OF NOISE SOURCES

would contain the same noise energy as the time-varying noise during the same period. As an example, in most stations a waiting passenger is likely to endure the arrival and/or departure of more than just one transit vehicle. The $L_{eq}$ represents the average sound energy which the patron experiences during the entire period he is waiting for a train.

$L_{eq}$ can be measured directly from the same recordings used to determine $L_A$(Max), or it can be determined analytically (See Appendices II and I). Like $L_A$(Max), inferences about the $L_{eq}$ at untested locations have been made in this report, by grouping sites and stations in terms of noise determinants.

When estimating $L_{eq}$ inside a transit car, one can use two definitions of average level to characterize sound levels along a route:

a. <u>Route Equivalent Sound Level, $L_{eq}$(R)</u>: $L_{eq}$(R) represents the average in-car sound level for the entire trip from one end of a route to another. $L_{eq}$(R) is useful in making comparisons between in-car environments on different routes or systems.

b. <u>Inter-Station Equivalent Sound Level, $L_{eq}$</u>: Representing the average in-car sound level between two stations, the inter-station $L_{eq}$ is indicative of the conditions of a specific segment of track and is useful in noise control analysis.

<u>Day-Night Equivalent Sound Level, $L_{dn}$</u>: The $L_{dn}$ is another noise energy measure, similar to $L_{eq}$, used to characterize the average sound level in the wayside community for a 24-hour period. Community $L_{dn}$ values include sound levels resulting from train pass-bys, as well as sound levels from other sources. The $L_{dn}$ weights nighttime sound levels (10 P.M. - 7 A.M.) more heavily than daytime sound levels. Unlike $L_{eq}$, which can be averaged over any period of time, $L_{dn}$ is always averaged over 24 hours, and thus has little practical usefulness for describing in-car or

in-station acoustic environments.

<u>$L_{dn}$ (Trains):</u> $L_{dn}$ (Trains) is a measure of the day-night equivalent sound level that results only from train pass-bys, excluding all other sources of community noise. Generally, $L_{dn}$(Trains) was not measured directly on the systems outlined in this report, but was calculated analytically, based on assumptions about time histories of noise from train pass-bys and using data from previous noise studies (see Appendix J).

<u>Ambient Community Sound Level, $L_{dn}$ (Ambient):</u> As indicated in a study prepared by Bolt, Beranek and Newman, Inc.,* the primary sources of background, or ambient, sound levels which are experienced by most community residents are surface transportation modes other than trains (i.e., automobiles and trucks). An empirically determined algorithm has been used to describe the ambient day-night equivalent sound levels which would exist in the wayside community without train pass-bys. This estimate of ambient community noise, called $L_{dn}$ (Ambient) in this report, is based on community population density, as discussed in Appendix J.

<u>Relative $L_{dn}$</u> - The Relative $L_{dn}$ for the wayside community is equivalent to the amount by which the $L_{dn}$, including noises from all sources, exceeds the $L_{dn}$ (Ambient). The significance of various levels of Relative $L_{dn}$ is discussed further in Appendix J.

## 2.3 EXPOSURE METHODOLOGY

The average maximum sound level, $L_A$(Max), is a fundamental measure which is useful in assessing the acoustic qualities of transit cars, stations, and track equipment. The $L_A$(Max) measure has been used for equipment design goals as noted in the following section.

*U.S. EPA, "Population Distribution of the United States as a Function of Outdoor Noise Level."

A substantial portion of this report has been devoted to documenting the range of maximum rail transit sound levels experienced by patrons and wayside residents. The number of stations and the amount of in-car route mileage with various $L_A$(Max) levels have been quantified. Residential areas in the wayside community have also been identified and related to the average maximum pass-by levels.

In assessing the exposure of patrons and wayside community residents to train noise, one should consider the duration as well as the magnitude of the transit noise event. Equivalent sound levels, such as $L_{eq}$ and $L_{dn}$, represent the average sound level for the period of exposure. As used in this report, equivalent levels also take into account the ambient, or background, noise from sources other than trains.

Equivalent levels have been directly measured in whole or in part on BART, RTA, PATCO, and SEPTA. For the remainder of the transit properties, $L_{eq}$ and $L_{dn}$ have been analytically determined using the measured $L_A$(Max) levels.

The Exposure sections of this report relate equivalent sound levels to the number of patrons who experience these levels during the transit trip. In addition, the estimated number of residents in the wayside community is related to the average community noise levels, including train pass-by noise, relative to what the community noise levels would be without trains.

The following sections explain generally the methodology used in applying equivalent sound levels. Methods of estimating the size of the population exposed are also discussed. More detailed explanations are included in Appendices H, I, and J.

### 2.3.1 Community (Wayside) Noise Exposure

To assess the exposure of the wayside community to train pass-by noise, an estimate has been made of the population living in the areas which are most significantly affected by train noise, i.e. residential areas. The extent of residential land within a 60-meter (200-ft.) corridor along both sides of the track has been related

to sound levels resulting from pass-bys, as indicated by average maximum sound levels, $L_A$(Max), and the day-night equivalent sound level, $L_{dn}$. Population density data has been used to estimate the size of the residential population within the 60-meter (200 ft) corridor along each side of the track.

A measure called Relative $L_{dn}$ has been used to give an indication of the impact of train pass-by noise relative to other community noise. The Relative $L_{dn}$ measure is equal to the difference between the overall community day-night equivalent sound levels, including train pass-bys, and the estimated ambient day-night equivalent sound levels which would exist if train noise were not present. Estimates are made of the proportion of the total wayside population which experiences noise levels represented by each value of Relative $L_{dn}$, as illustrated in Figure 2-9.

### 2.3.2 In-Car Noise Exposure

Two methods are used in this report to assess the exposure of transit car passengers to in-car noise. In lieu of specific information on work trip time for riders on individual transit routes throughout the country (not available for this analysis), both of these methods impose a national pattern of public transit ridership by two-day work trip time on each transit system route. This ridership distribution, taken from a national survey of public transit use, is shown in Figure 2-10. For average trip times, it seems to correlate well with average rapid transit trip length information found elsewhere, despite obvious discrepancies with respect to very long two-way trips (i.e., greater than 100 min.) not possible along some routes.

In-car noise exposure can be determined by assuming that the riders on any part of a route (as defined by the national survey distribution) are subjected to the equivalent level characterizing the entire route, $L_{eq}$ (R), for the length of time they travel along the route. For example, Figure 2-10 indicates that 22 percent of the patrons ride for 50 minutes a day. On a transit route having

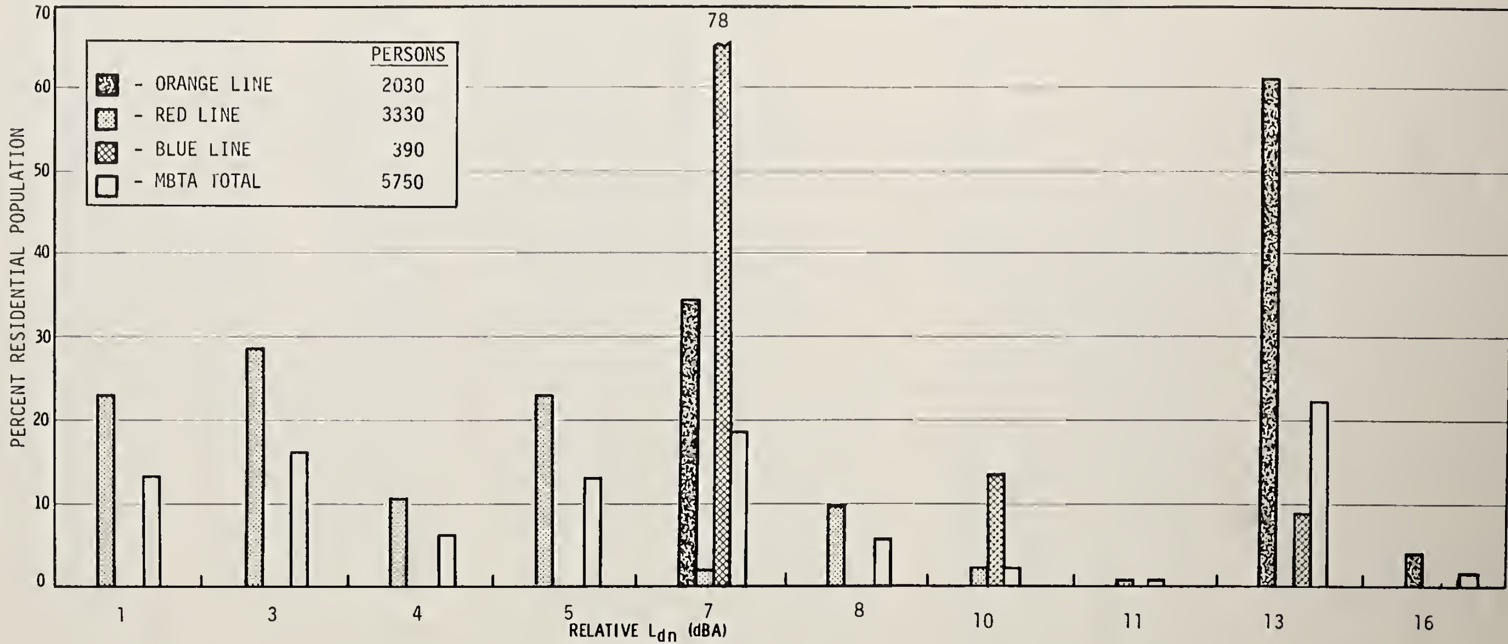



FIGURE 2-9 MBTA SYSTEM, WAYSIDE NOISE EXPOSURE

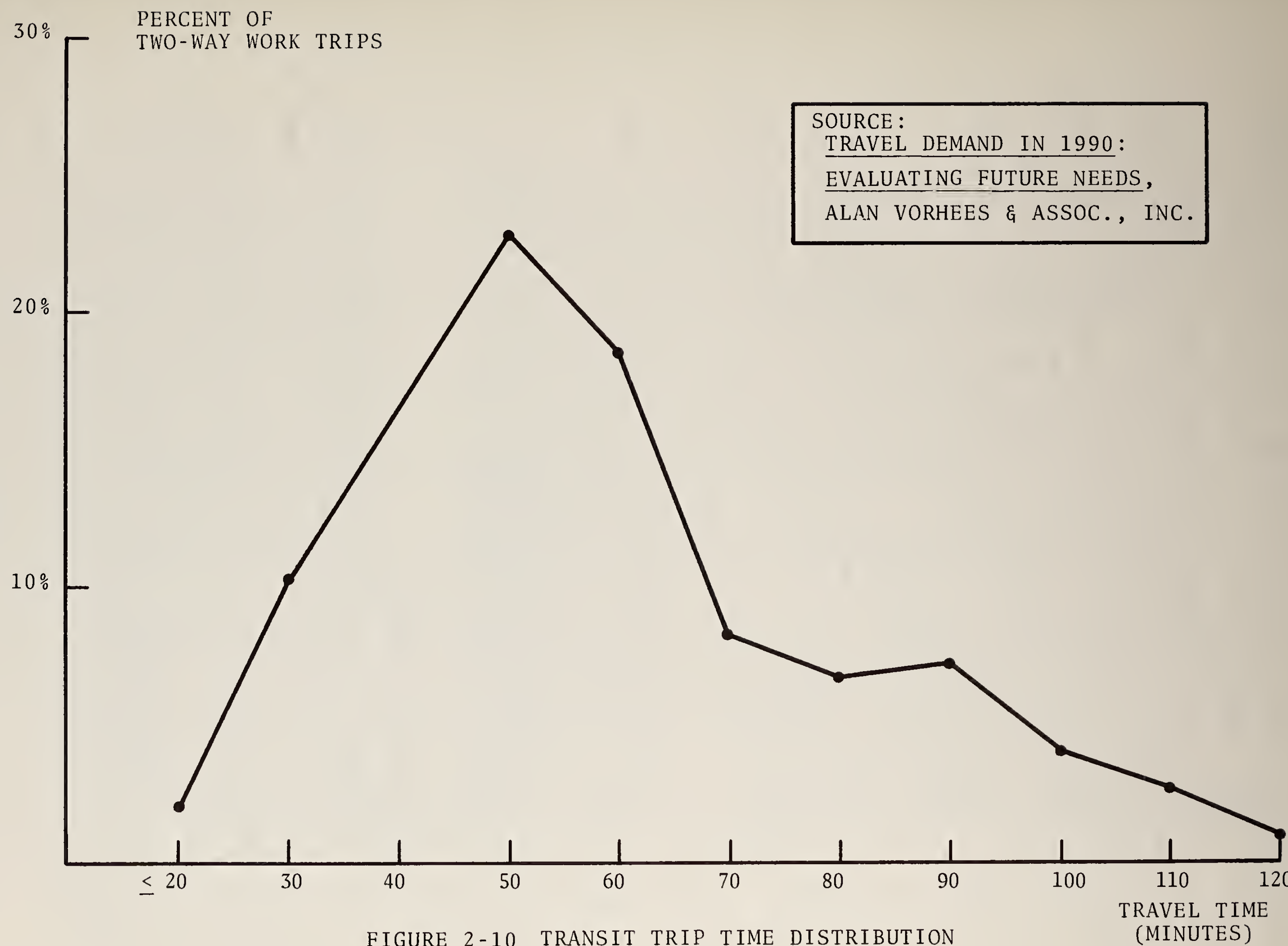



FIGURE 2-10 TRANSIT TRIP TIME DISTRIBUTION

600 riders per day and an $L_{eq}(R)$ of 80 dBA, 132 riders (22 percent x 600 riders) are exposed to an $L_{eq}$ of 80 dBA for 50 minutes.

The other method of estimating passenger exposure imposes ridership information on a distribution of route mileage by inter-station (rather than average route) $L_{eq}$ values. Because data on the origins and destinations of individual passengers were unavailable, the assumption was made that the distribution of sound levels for each rider's trip was equivalent to that of the entire route. For example, if 20 percent of the route mileage can be represented by $L_{eq}$ values between 75 and 80 dBA, then 20 percent of each rider's trip is assumed to pass over links where $L_{eq}$ has been evaluated at between 75 and 80 dBA. The national trip time distribution, Figure 2-10, is weighted by the total patronage on the route, giving a measure of ridership/trip duration expressed in terms of people-hours. The total number of people-hours for a route is then distributed over the in-car inter-station $L_{eq}$ values, resulting in a distribution of exposure such as that shown in Figure 2-11.

A more detailed description of in-car exposure could be made using the information given in exposure distributions such as Figure 2-11. If accurate average trip times for a system, not available for this analysis, were given, one could specify the average time exposed to in-car $L_{eq}$ levels, and the total number of patrons exposed to each level.

### 2.3.3 In-Station Noise Exposure

To represent in-station noise exposure, the equivalent sound levels, $L_{eq}$, used to characterize the noise levels in each transit station have been related to transit property information concerning expected numbers of patrons in each station. The resulting distributions show the percent of total patronage exposed to each level of station $L_{eq}$, as the distribution in Figure 2-12 indicates. This histogram shows that more than 50 percent of the patrons on the MBTA system wait at stations where the equivalent sound level is between 76 and 80 dBA.

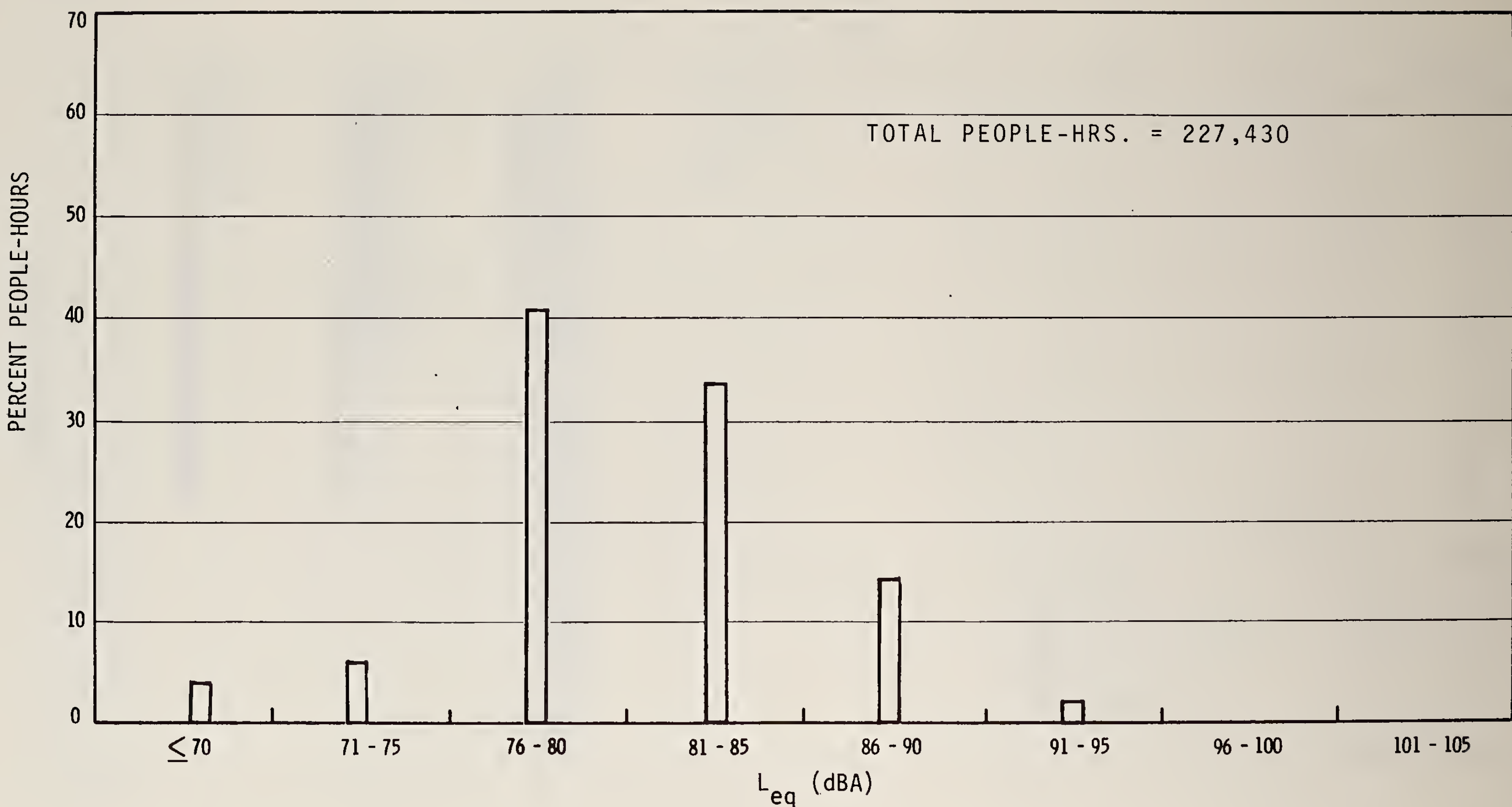



FIGURE 2-11 MBTA SYSTEM, IN-CAR NOISE EXPOSURE

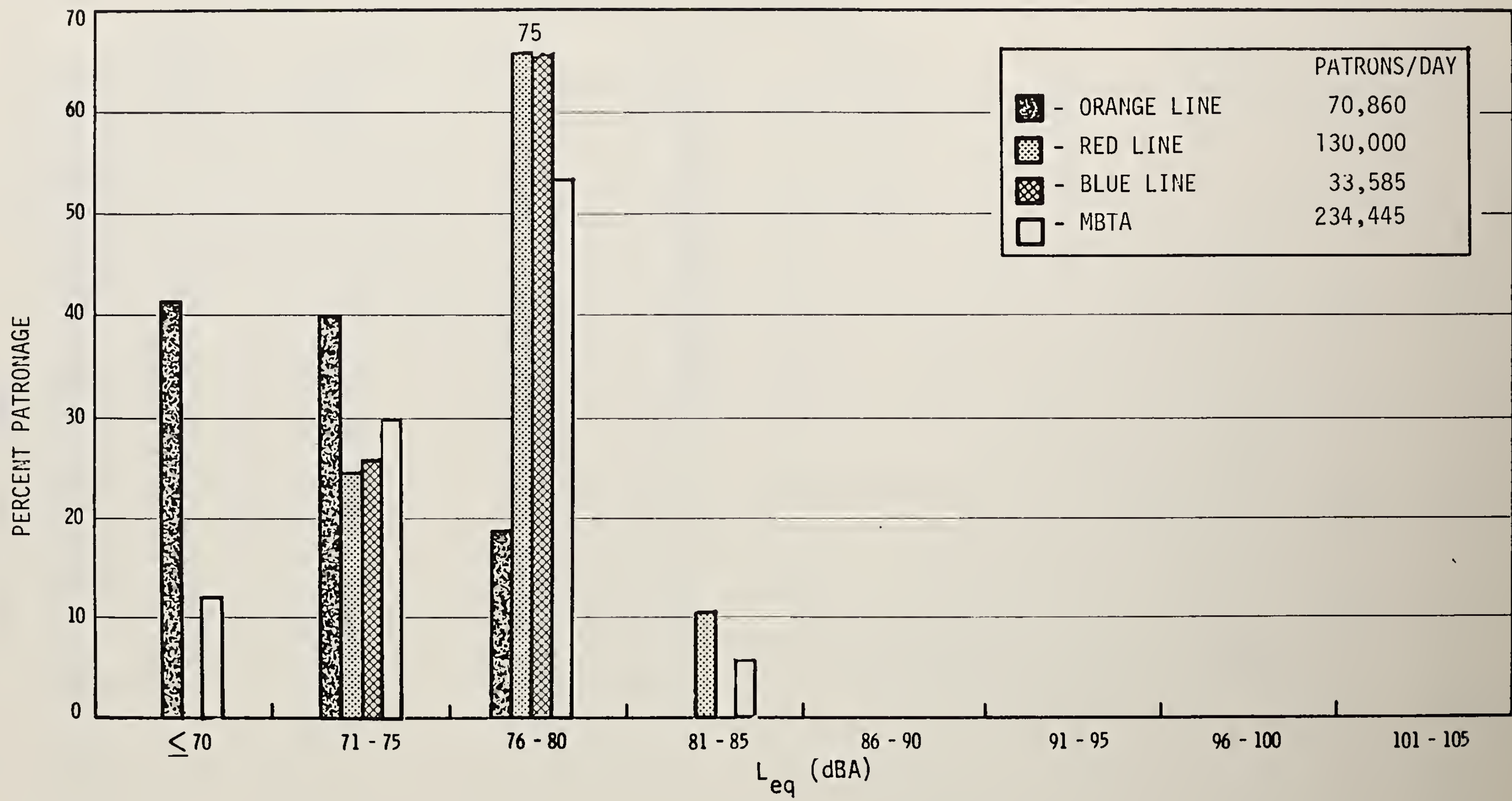



FIGURE 2-12 MBTA SYSTEM, IN-STATION NOISE EXPOSURE

# 3. GUIDELINES FOR URBAN RAIL NOISE

For evaluation purposes, we have compared each noise assessment made in our study on the respective transit systems with the guidelines* established by the American Public Transit Association (APTA) for new systems and extensions. Such comparisons show the differences which may exist between the noise levels in one of the older systems and in a newer system. Together with the environmental noise guidelines that are included here, they serve as a partial basis for policymaking on the local, state and Federal levels. Other factors such as the feasibility of noise control methods, cost, and political and institutional factors quite clearly will also influence noise abatement policies and decisions.

## 3.1 APTA GUIDELINES

The APTA Guidelines with which we have compared our findings were prepared by the transit industry association, representing public and private transit operators. In reviewing these Guidelines, one should be aware that the transit operators are confronted with demands for low fares, special services to the handicapped and elderly, reduced subsidies, improved reliability and productivity, and higher service levels, all of which compete with the demand for quieter and more comfortable facilities and reduced wayside noise. In comparing the APTA Guidelines with noise criteria and standards of Federal agencies such as the FHWA and the EPA, one should keep in mind the different roles each organization plays within the overall context of transportation noise control.

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*American Public Transit Association, "Guidelines for Design of Rapid Transit Facilities," Section 2-7, "Noise and Vibration."

### 3.1.1 In-Car Noise Levels (Empty Car)

A sound level of 70 dBA* is recommended as the acceptable maximum for in-car noise. It is maintained that this sound level will provide a background that will afford speech privacy, passenger comfort, and that it is "... a realistically attainable criterion and datum upon which other noise design goals can be based."

The criterion is established for trains operating at maximum speeds on ballast and tie track using welded rail, in the open. For other conditions such as jointed rail, concrete trackbed, a higher sound level is indicated as a noise design objective. A summary of the criteria is given in Table 3-1.

TABLE 3-1 SUMMARY OF APTA IN-CAR NOISE DESIGN GOALS

| Item | Goals |
|---|---|
| Vehicle Interior Noise Levels (Empty Car) | $L_A$(Max) |
| In open (ballast and tie) at maximum speed on welded rail (+5 dBA on jointed rail) | 70 dBA |
| In open (concrete trackbed) at maximum speed at-grade or on an aerial structure | 74 dBA |
| In tunnels at maximum speed | 80 dBA |

In-car design goals may be converted from $L_A$(Max) to $L_{eq}$ by applying the empirically derived relationship:

$L_{eq} = L_A(\text{Max}) - 2.2$ dBA (See Appendix H).

The APTA Guidelines also provide design goals for vehicle interior vibration levels generated by auxiliary equipment. These are not discussed here since corresponding measurements were not made in our study.

*Unless otherwise noted, criteria cited here are from the APTA Guidelines for newly constructed systems.

The APTA Guidelines state: "In all vehicles for conveyance it is desirable to maintain a background sound level which will afford some degree of speech privacy for passengers." What this implies is that a high enough background sound level will interfere with the hearing of those just beyond the immediate vicinity in which a conversation is taking place. In other words, beyond a certain distance the conversation will be masked by the background sound. If the background sound level is too high, communication between passengers becomes more difficult; they must raise their voices, perhaps to the point of shouting; and they must decrease the distance between them in order to be heard. Therefore, "speech privacy" is related to the maximum permissible level of background noise, referred to as the preferred speech interference level (PSIL).

The PSIL is computed by averaging the sound levels centered at the 500, 1000, and 2000 Hz octave bands; for noise which does not have a preponderance of high frequency sound energy it is well estimated by dBA meter readings.

Table 3-2 shows the voice effort required (normal, raised, loud) for male and female voices at a distance of three feet when the speech interference levels are those given in the table. Speech interference levels for female voices are generally about five dBA less than those for male voices.

TABLE 3-2 VOICE EFFORTS FOR SPEECH INTERFERENCE LEVELS AT THREE FEET*

| VOICE EFFORT | PSIL, dB | |
|---|---|---|
| | MALE | FEMALE |
| Normal | 59 (67 dBA) | 54 (62 dBA) |
| Raised | 67 (73 dBA) | 62 (68 dBA) |
| Loud | 72 (79 dBA) | 67 (74 dBA) |

*Derived from: L.L. Beranek, ed., Noise and Vibration Control, Chapter 18, Section 18.1; and John C. Webster, "SIL--Past, Present, and Future," Sound and Vibration, August 1969, p. 22-26.

The APTA Guideline proposes 70 dBA as the design goal for vehicle interior noise levels in the open at maximum speeds over ballast and tie track construction with welded rail. The frequency spectrum generated by a well-designed car over this type of track construction* would result in a PSIL of approximately 63 dB. The implications of the APTA in-car design goals, in terms of speech interference for both male and female voice levels, for different types of track construction, in the open and in tunnels, are shown in Table 3-3. The dBA values in the table are those given in the APTA Guidelines; the PSIL values are based on these noise levels, assuming spectra like those shown in Manning et al., (1974). For female voices lower levels may be desirable although, in some instances, the background sound level required for speech privacy is higher than that which would be desired solely for intelligibility; therefore, some compromise is generally necessary in setting noise design goals.

### 3.1.2 Station Noise Levels

In setting noise design goals for rail transit stations, APTA takes into consideration such factors as the method of train operations, the case of express (non-stop) trains, the noise from stationary trains, and the effect of reverberating sound on the intelligibility of communication over public address systems in underground stations. The assumption was made that, in new systems, trains may be operating at top speeds of 130 km/h (80 mph), and, using maximum acceleration and braking levels, would enter and leave stations at a speed of 80 km/h (50 mph).

According to the APTA Guidelines, the design goals may be met provided that resilient track fixation and absorptive materials are applied. In most underground stations, underplatform overhang surfaces and about 30 percent of the walls and ceilings would have

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*J.E. Manning, R.J. Cann, J.J. Fredberg, "Prediction and Control of Rail Transit Noise and Vibration: A State-of-the-Art Assessment," Figure 5.1, p. 102.

TABLE 3-3 APTA IN-CAR NOISE DESIGN GOALS AND SPEECH INTERFERENCE

| Type of Track Construction And Structure | Estimated Background Noise Level Using Apta Design Goals as a Basis* | Distance From Speaker to Listener (In Feet) | Face-to-Face Conversational Level: Male Voices | Face-to-Face Conversational Level: Female Voices |
|---|---|---|---|---|
| Open, ballast & tie, max. speeds: | | | | |
| Welded rail | 70 dBA (63 dB PSIL) | 1.0 | normal | normal |
| | | 2.0 | normal | raised |
| | | 3.0 | normal-raised | raised |
| Jointed rail | 75 dBA (68 dB PSIL) | 1.0 | normal | raised |
| | | 2.0 | raised | very loud |
| | | 3.0 | raised | very loud |
| Open, concrete track bed, max. speeds, at-grade or aerial structure | 74 dBA (67 dB PSIL) | 1.0 | normal | raised |
| | | 2.0 | raised | very loud |
| | | 3.0 | raised | very loud |
| In tunnels, max. speeds | 80 dBA (73 dB PSIL) | 1.0 | raised | very loud |
| | | 2.0 | very loud | very loud-shouting |
| | | 3.0 | very loud | very loud-shouting |

*APTA design goals were converted to $L_{eq}$ values and used as the background noise levels. The nomograph used to determine face-to-face conversational levels, is Figure 1, Webster, "SIL--Past, Present, and Future."

to be covered with the absorptive materials. In aboveground stations, transit patrons may be exposed to noise from other sources such as highways, railroads, or airports.* Shielding against noise from these sources, as well as from the transit system itself, is recommended, unless it is impractical to do so.

The noise design goals are summarized in Table 3-4 below. Applying these design goals to the example of the MBTA Red Line one can establish the empirically derived relationship between $L_A(\text{Max})$ and $L_{eq}$ of $L_{eq} = L_A(\text{Max}) - 9$ dBA.

TABLE 3-4 SUMMARY OF STATION AND TUNNEL NOISE DESIGN GOALS

| Item | Goals<br>Maximum Noise Level Limits |
|---|---|
| Underground Stations | |
| Platform noise level, trains entering and leaving | 80-85 dBA |
| Platform noise level, trains passing through | 85 dBA |
| Platform noise level, trains stationary | 68 dBA |
| Platform area reverberation time (for large cross-section multi-track platform areas) | 1.2 to 1.4 sec (1.4 to 1.6 sec) |
| Platform noise level, only station ventilating system and escalators operating | 55 dBA |
| Noise level in station attendants' booths | 50 dBA |
| Noise in Aboveground Stations (at-grade or elevated) | |
| Platform level, trains entering and leaving: | |
| ballast and tie track | 75-80 dBA |
| concrete trackbed | 80-85 dBA |
| Noise in Subway Tunnels | |
| Minimum useful design reduction in reverberant noise levels with acoustic treatment | 7 dBA |

*See the description of the Chicago Transit Authority System in Appendix F.

### 3.1.3 Wayside Noise Design Goals

In its approach to wayside noise, APTA proposes a set of guidelines in terms of five different community area categories (See Table 3-5) and three different building types. The guidelines are predicated upon certain prescribed permissible differences between maximum pass-by levels and the typical (average) ambient noise levels in each of the community area categories. The ambient levels are shown in Table 3-5.

The characterization of these categories is imprecise: no quantitative definitions are given for either the density classifications or the land use designations in areas of mixed land use. The sources of data for the association of ambient levels with the community categories are not given.

These guidelines are to be applied to nighttime operations, referenced to "the buildings or area under consideration" but not closer than 50 feet from the track center-line. Nighttime hours, not defined in the APTA guidelines, are customarily from 11:00 P.M. to 7:00 A.M. (In applying these values to the example, in which $L_{dn}$ values are computed, it is assumed that the same noise levels will be maintained at night and in the daytime.) The referencing of the design goal to "the buildings or area under consideration" is ambiguous since the noise levels at the property line, the building face, or at some other point, can differ. Providing noise design level goals at various distances from the track center-line would be a more precise guide and would allow for future development and change in the transit corridor.

In the APTA guidelines each of the five community categories is associated with the median, $L_{50}$, noise level (which is also termed the "ambient" noise level). The $L_{50}$ noise level is the level which is exceeded 50 percent of the time over a specified period. In the APTA guidelines the $L_{50}$ noise levels are given for "day" and "night," as shown in Table 3-5.

In order to gain a more quantitative understanding of the APTA community categories, densities for each category have been derived. It is believed that these densities will be helpful to

TABLE 3-5 GENERAL CATEGORIES OF COMMUNITIES ALONG TRANSIT SYSTEM CORRIDORS

| Area Category | Area Description | Typical Ambient Noise Level ($L_{50}$*) |
|---|---|---|
| I | Low density urban residential, open space park, suburban, | 40-50 dBA - day<br>35-45 dBA - night |
| II | Average urban residential, quiet apartment and hotels, open space, suburban residential, or occupied outdoor area near busy streets. | 45-55 dBA - day<br>40-50 dBA - night |
| III | High density urban residential, average semi-residential/commercial areas, parks, museum and non-commercial public building areas. | 50-60 dBA - day<br>45-55 dBA - night |
| IV | Commercial areas with office buildings, retail stores, etc., primarily daytime occupancy. Central business district. | 60-70 dBA |
| V | Industrial areas or freeway and highway corridors. | Over 60 dBA |

*$L_{50}$ is the median noise level.

urban planners and transportation analysts in evaluating the guidelines and their application in this study. The densities were derived from empirical relationships between population density and noise levels*, which were then applied to the APTA guidelines. They should be regarded as rough approximations only. The densities, in terms of people per square mile and dwelling units per acre, are given in Table 3-6.

TABLE 3-6 DENSITIES OF COMMUNITY AREA CATEGORIES

| AREA CATEGORY | | AVERAGE PEOPLE/SQ. MI. | TYPICAL DWELLING UNITS/ ACRE** |
|---|---|---|---|
| Community Area Category | | | |
| I | Low Density Residential | 600 | 0.3 to 1 |
| II | Average Urban Residential | 2000 | 3 |
| III | High Density | 6000 | 12-35 |
| IV | Commercial | N.A. | N.A. |
| V | Industrial | N.A. | N.A. |

APTA design goals are given in terms of a single event maximum noise level for each community category. Within each category a different design goal is indicated in terms of the building type which presumably is predominant in the wayside areas: single family dwellings, multifamily dwellings, and commercial buildings, as shown in Table 3-7.

*See U.S. EPA, "Population Distribution of the United States as a Function of Outdoor Noise Level," and National Research Council Committee on Hearing, Bioacoustics, and Biomechanics, "Guidelines for Preparing Environmental Impact Statements on Noise," Table IV-1, p. IV-7.

**Acres are gross acres comprising residential land, streets, and playgrounds.

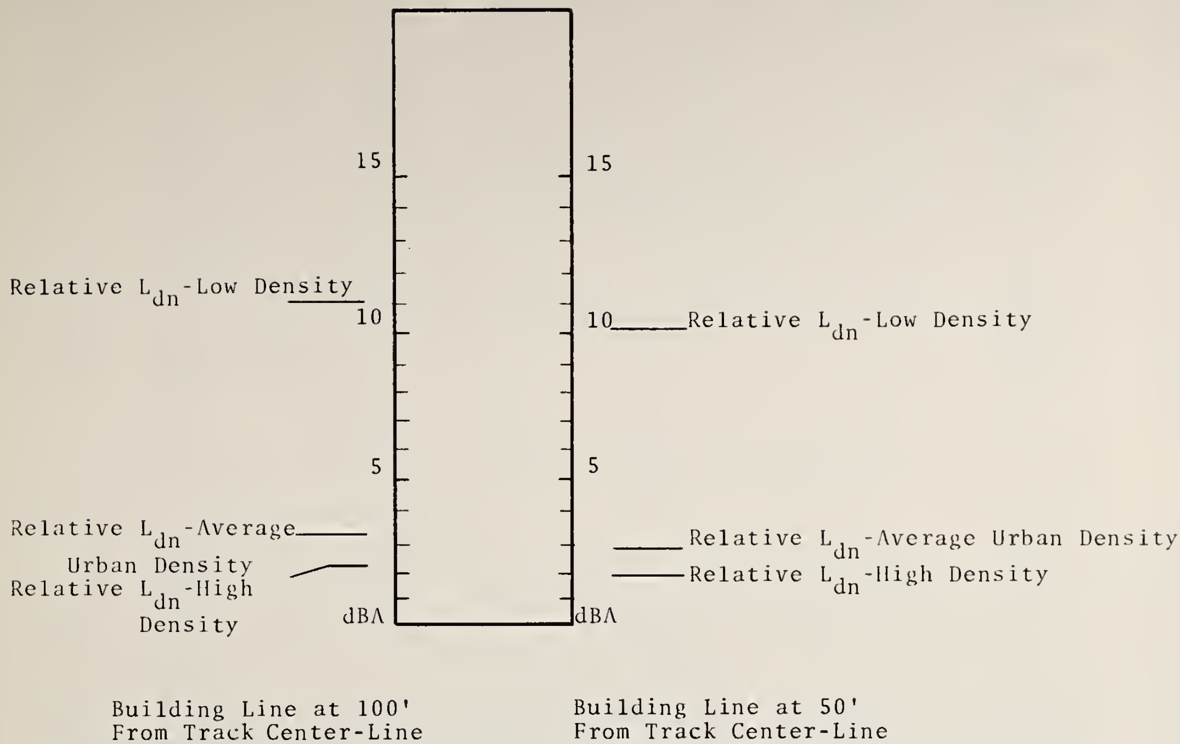
TABLE 3-7 APTA GUIDELINES FOR MAXIMUM AIRBORNE NOISE FROM TRAIN OPERATIONS

| Community Area Category | Single Event Maximum Noise Level Design Goal | | |
|---|---|---|---|
| | Single Family Dwellings | Multi-Family Dwellings | Commercial Buildings |
| I Low Density Residential | 70 dBA | 75 dBA | 80 dBA |
| II Average Residential | 75 | 75 | 80 |
| III High Density Residential | 75 | 80 | 85 |
| IV Commercial | 80 | 80 | 85 |
| V Industrial/Highway | 80 | 85 | 85 |

The APTA wayside design goals permit higher noise levels in areas with higher residential densities. However, because average, or $L_{50}$, noise levels are higher at higher densities, the height of the single event noise peak $L_A$(Max) above the average noise level is approximately the same (within 5 dBA) for a given building type across the three residential densities. When the noise impacts are viewed in terms of energy using Relative $L_{dn}$ as the measure, i.e., $L_{dn}$ (resulting from all noise sources) minus $L_{dn}$ (Ambient), Relative $L_{dn}$ decreases as density (and average noise level) increases; that is, the noise energy of the train pass-bys is a relatively smaller proportion of the total environmental noise energy to which residents are exposed. This is indicated in Figure 3-1.

Although noise is attenuated with distance, the effective duration of exposure to noise increases with distance. As a result of these two counteracting factors, the relative $L_{dn}$ at 100 feet is slightly greater than that at 50 feet.

Table 3-8 presents the APTA wayside noise level design goals in terms of $L_A$(Max), $L_{eq}$, and $L_{dn}$ (trains only) at a distance of 50 feet using parameters from the MBTA Red Line. These are related to population density levels for the various residential categories and the total $L_{dn}$ levels in each category.




*Based on MBTA Red Line Train Parameters - 3 (70') Car Trains 144 Day, 30 Evening, 37 Night Passbys at 33 Mph (See Appendix J).

FIGURE 3-1 RELATIVE $L_{dn}$ - ASSUMING TRAIN PASS-BY SOUND LEVELS WERE AT APTA GOALS FOR AVERAGE RESIDENTIAL AREAS

TABLE 3-8 APTA DESIGN NOISE LEVELS APPLIED TO AN EXAMPLE SHOWING RESULTING OUTDOOR YEARLY DAY-NIGHT AVERAGE SOUND LEVELS FOR VARIOUS RESIDENTIAL CATEGORIES

| APTA CATEGORIES | Noise Measures | DESIGN LEVEL FOR TRAINS @ 50 FEET* A 1-family dwellings | B Multi-family dwellings | C Commercial industrial highway | Average Census Tract Population Density, Number of People Per Square Mile | Estimated Percentage of Population at this Density | Total $L_{dn}$** Using APTA Design Levels A | B | C | Outdoor $L_{dn}$ in Urban Areas*** | Desirable Outdoor $L_{eq}$ EPA Criteria |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I LOW | $L_A$ MAX | 70 dBA | 75 dBA | 80 dBA | | | 57 dB | 62 dB | 67 dB | | |
| DENSITY | $L_{eq}$ 24 | 53 dB | 58 dB | 63 dB | 600 | 12 | to | to | | | |
| RESIDENTIAL | $L_{dn}$ | 57 dB | 62 dB | 67 dB | | | 59 dB | 63 dB | | 50 dB | 55 dB |
| II AVERAGE | $L_A$ MAX | SAME | SAME | SAME | | | 62 dB | 62 dB | 67 dB | | |
| RESIDENTIAL | $L_{eq}$ 24 | AS | AS | AS | 2000 | 21 | to | to | to | 55 dB | 55 dB |
| | $L_{dn}$ | I B | I B | I C | | | 64 dB | 64 dB | 68 dB | | |
| III HIGH | $L_A$ MAX | SAME | SAME | 85 dBA | | | 63 dB | 67 dB | 72 dB | | |
| DENSITY | $L_{eq}$ 24 | AS | AS | 68 dB | 6000 | 28 | to | to | to | 60 dB | 55 dB |
| RESIDENTIAL | $L_{dn}$ | I B | I C | 72 dB | | | 66 dB | 69 dB | 73 dB | | |
| IV | $L_A$ MAX | SAME | SAME | SAME | | | | | | | |
| COMMERCIAL | $L_{eq}$ 24 | AS | AS | AS | | | | | | | |
| | $L_{dn}$ | I C | I C | III C | | | | | | | |
| V INDUSTRIAL | $L_A$ MAX | SAME | SAME | SAME | | | | | | | |
| HIGHWAY | $L_{eq}$ 24 | AS | AS | AS | | | | | | | |
| | $L_{dn}$ | I C | III C | III C | | | | | | | |

NOTES: *$L_{eq}(24)$ and $L_{dn}$ (trains only) values are based on MTBA Red Line parameters of 144 day, 30 evening, and 39 night pass-bys; 2.81 cars/train; 22.9-meter cars; 14.7 m/sec.; at 50 feet from near track.

**Total $L_{dn}$ is the level resulting from combining $L_{dn}$ (trains only) and $L_{dn}$ (ambient).

***Based on relationship with average population densities; $L_{dn} = 10 \log(\rho) + 22$.

## 3.2 COMPARISON OF APTA WAYSIDE NOISE DESIGN GOALS WITH EPA GUIDELINES

Certain documents prepared by the Environmental Protection Agency (EPA) are referred to in the APTA Guidelines in connection with the effects of noise. These are listed in the Bibliography, Section 6.

One feature of the APTA Guidelines, the relating of community and building type categories to ambient or average noise levels, has its basis in the EPA documents. Beyond this, the approaches of the APTA Guidelines and the EPA documents are dissimilar, and a comparison and application of the two provides insights into the strengths and weaknesses of each. The comparison also brings out some of the issues and difficulties inherent in the control of transportation noise.

The APTA guidelines are intended for immediate application as design goals. In contrast, the EPA criteria are intended as desirable long-range goals.

The EPA maximum level criterion for an individual's daily noise exposure is a 24-hour $L_{eq}$ value of 70 dB, which is based on the risk of hearing loss at critical speech frequencies. In addition, EPA would limit the $L_{eq}$ to 60 dB in residential areas to prevent the sleep of residents from being disturbed.

The APTA guidelines apparently are not addressed primarily toward the prevention of hearing loss but are clearly intended to protect the sleep of residents in wayside areas, since the guidelines are applied to <u>nighttime</u> operations. The APTA guidelines are expressed in terms of $L_A$(Max) rather than in terms of 24-hour $L_{eq}$. In an example in which MBTA Red Line parameters are applied, the equivalent $L_{eq}24$ values would range from 53 dB to 68 dB, depending upon the design goals for each land use and density category. Also included in the APTA guidelines are goals for special occupancies or building types, regardless of the land use or density category in which they happen to be located. For these occupancies, the $L_A$(Max) values range from 60 to 75 dBA,

corresponding to $L_{eq}$=43 to $L_{eq}$=58 dB, based on MBTA Red Line parameters.

EPA has identified $L_{dn}$=55 dB as the sound level for residential areas which is "compatible with the protection of public health and welfare." A comparison of this guideline with existing conditions as indicated in EPA surveys and estimates shows that the majority of the 134 million people living in urban areas (1970) are exposed to outdoor $L_{dn}$ values ranging from 43 to 72 dB, with a median value of 59 dB.

In assessing the impact of noise, the sound level indoors is of critical importance. Typically, the sound level indoors resulting from the transmission of outdoor sound would be expected to be 15 dB less than the outdoor level. An EPA survey has shown that, in a sample of 12 houses, the interior $L_{dn}$ resulted from internally generated sound rather than from the transmission of outdoor sound.

## 3.3 COMPARISON OF APTA AND FHWA DESIGN NOISE LEVEL GUIDELINES

The most pervasive environmental noise in urban areas is that generated by road traffic. For the most part, the background noise levels in urban areas are determined by the level of automotive traffic. Residential and other noise-sensitive areas adjacent to highways are exposed to high levels of noise. In response to this problem, Federal Highway Administration (FHWA) has developed noise level guidelines* as a means of reducing the noise of the interstate highway system. In this section the APTA and FHWA guidelines for wayside noise will be contrasted.

In making this comparison it must be recognized that rail traffic and highway traffic differ because, in each case, different noise-generation mechanisms are at work. As a result, although each guideline deals with the problem of controlling or reducing wayside noise levels, the numerical values selected as the design goals do not necessarily have to agree. These numerical values, nevertheless, are of interest if one wishes to assess the relative impacts of rail and highway noise in urban areas.

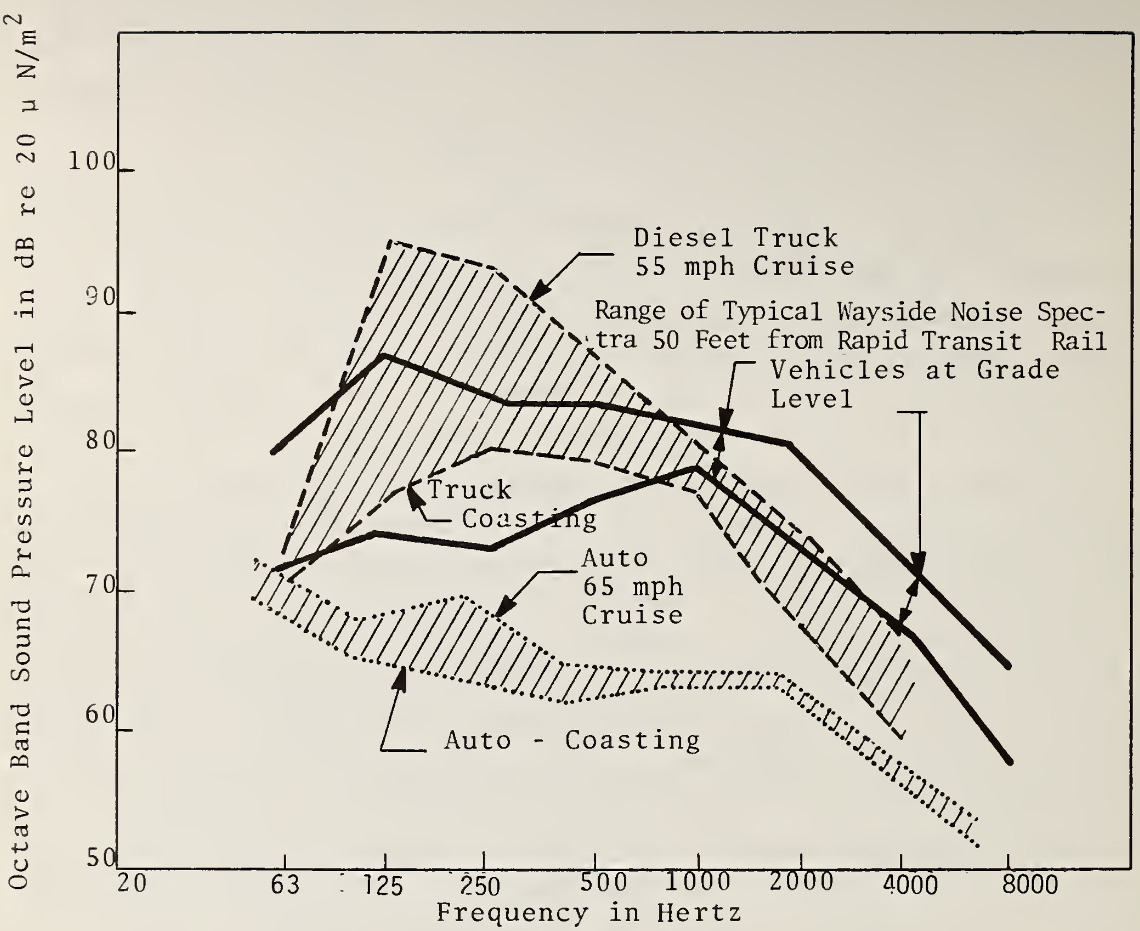
*FHWA, Federal-Aid Highway Program Manual, Transmittal 205.

One of the most obvious differences between rail and highway traffic noise is that transit trains run on a regular schedule whereas most pass-bys of motor vehicles on highways are random. In addition to the distribution of the noise, the noise sources, and hence, noise spectra, are different. The principal source of rail transit noise is wheel-rail interaction, with propulsion system noise becoming increasingly important at high speeds. In automotive traffic, engine and muffler noise is dominant at lower speeds, and tire noise is dominant at higher speeds.

The intensities and the frequency spectra are different for truck noise and rail transit noise. Figure 3-2 shows wayside noise levels and spectra for diesel truck, automobile, and rail transit. At the lower frequencies, 90 Hz to 1000 Hz, diesel trucks have sound levels that are 8 to 10 dB greater than those for rail transit. Since the lower sound frequencies tend to be transmitted through buildings more readily than high frequencies, one would expect greater annoyance to be associated with truck noise than with rail transit noise, at the same outdoor A-weighted level.

FHWA sets up various "activity categories" which correspond to APTA's "community categories." However, the FHWA approach is simpler in that there are only three major categories for built-up areas, as well as a provision for undeveloped areas, and an interior noise level standard for noise-sensitive uses. All the residential areas, regardless of density, are included in one category. Noise-sensitive occupancies, e.g., hospitals, libraries, schools, are included in the same category as residential uses.

FHWA permits use of either $L_{10}$ or $L_{eq}$ as the measure of the design noise level (but not both). The $L_{10}$ noise level is the level which is exceeded 10 percent of the time over the period which is measured; therefore, it indicates both the frequency of occurrence and magnitude of the loudest noise events. No distinction is made between daytime and nighttime operations. The FHWA design noise levels are shown in Table 3-9.




Source: Adapted from EPA, "Transportation Noise and Noise from Equipment Powered by Internal Combustion Engines."

FIGURE 3-2 WAYSIDE NOISE LEVELS AND SPECTRA FOR DIESEL TRUCK AND AUTOMOBILE NOISE AT HIGHWAY SPEEDS, CRUISE AND COASTING (AT 50 FEET), AND RAIL TRANSIT VEHICLES AT-GRADE AT 50 FEET

TABLE 3-9 FHWA DESIGN NOISE LEVEL/ACTIVITY RELATIONSHIPS

| Activity Category | Design Noise Levels - dBA | | Description of Activity Category |
|---|---|---|---|
| | $L_{eq}(h)$ | $L_{10}(h)$ | |
| A | 57 (Exterior) | 60 (Exterior) | Tracts of land in which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose. Such areas could include amphitheaters, particular parks or portions of parks, open spaces, or historic districts which are dedicated or recognized by appropriate local officials for activities requiring special qualities of serenity and quiet. |
| B | 67 (Exterior) | 70 (Exterior) | Picnic areas, recreation areas, playgrounds, active sports areas, and parks which are not included in Category A and residences, motels, hotels, public meeting rooms, schools, churches, libraries, and hospitals. |
| C | 72 (Exterior) | 75 (Exterior) | Developed lands, properties or activities not included in Categories A or B above. |
| D | --- | --- | Requirements on undeveloped lands related to prior knowledge of highway projects and to planning and design to control noise. |
| E | 52 (Interior) | 55 (Interior) | Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums. |

SOURCE: FHWA, Federal-Aid Highway Program Manual.

## 3.4 A CASE STUDY: APPLYING APTA GUIDELINES TO AN EXISTING TRANSIT LINE

In order to compare APTA's guideline values with EPA's criteria we present an example based on the MBTA's Red Line in Boston. In this comparison the noise levels are hypothetical, not actual values. They are derived by assuming a set of $L_A$(Max) values at 50 feet, equal to the APTA design goals. This is the condition that would exist if the line were modernized so as to meet the goals.

Using these $L_A$(Max) values, and MBTA Red Line parameters for number of pass-bys at various periods, the average size of trains, car lengths, and speed, we derive the $L_{eq}$ (24) and $L_{dn}$ values for trains at 50 feet. $L_{dn}$(Ambient) values were derived from typical $L_{50}$ values given in the APTA Guidelines for day and night in each residential category. Then these values were combined with the $L_{dn}$(Trains) values (through decibel addition) to obtain total $L_{dn}$. Since the ambient values were given in terms of a range for three different building densities within each category, the total $L_{dn}$ values were given in a similar fashion.

The median outdoor $L_{dn}$ in urban areas, as estimated by EPA (see supra, p. 3-14) and the EPA criteria for outdoor $L_{dn}$ are shown in Table 3-8 for the purpose of comparison. In the Low-Density/One-Family Dwelling classification the $L_{dn}$ (total) is lower than the median outdoor $L_{dn}$. In all other classifications the median is exceeded. None of the classifications meet the EPA criteria.

Noise level values change as train speeds and headways vary. The effects of such variations are explained in Appendix J.

## 3.5 CHABA GUIDELINES

In June 1977, the Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) of the National Research Council published "Guidelines For Preparing Environmental Impact Statements On Noise." These guidelines have been proposed as a uniform national method for assessing noise impacts. The CHABA document is based on

essentially the same criteria that are embodied in the EPA "levels document."* Interference with speech, with general well being, and with sleep, as expressed in terms of annoyance, is accepted as an indication of the effects of noise on public health and welfare. A threshold of $L_{dn}$ = 55 is accepted as the level below which there are no significant impacts on health and welfare. The EPA criterion for protection against hearing loss is a 24-hour $L_{eq}$ value of 70 dBA. CHABA's criterion for protection against hearing loss is an $L_{dn}$ of 75 dB. They are roughly equivalent.

Although the criteria are approximately the same, the methodology used by CHABA is markedly different from that used by EPA. CHABA uses a new concept, that of "sound level-weighted population," which is derived from summing the increments of the cumulative percentages of the population exposed to various noise levels multiplied by a sound level weighting value. The weighting value is derived empirically from social surveys of populations living in noise-impacted environments. The populations under consideration may reside in any geographic area under study: the nation, a region, a metropolis, or a locality.

Another measure developed by CHABA is population-weighted loss of hearing, which is a second weighting function to be applied when the day-night average sound level in a residential area exceeds 75 dB. Since, in many cases, good data on population distributions in various environments are lacking, adoption of the CHABA methodology calls for extensive survey activity in order to generate additional data.

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*EPA, "Information on Levels of Environmental Noise Requisite With an Adequate Margin of Safety."

## 3.6 A SUMMARY THREE-WAY COMPARISON OF EPA, APTA, AND FHWA GUIDELINES

A three-way comparison of EPA, APTA, and FHWA guidelines is shown in Table 3-10. For convenience, all noise level values are given in terms of $L_{eq}$ 24 and $L_{dn}$. Where $L_{dn}$ is not applicable, e.g., in commercial and industrial areas in which there are primarily daytime activities, $L_{dn}$ is not given.

The noise level values, ($L_{eq}$ 24, $L_{dn}$) shown for APTA are based on MBTA Red Line parameters, assuming that the line met APTA design goals. Both APTA and FHWA exceed the EPA criterion of an $L_{dn}$ of 55 dB in residential areas.

The EPA criterion is intended to provide for normal speech communication outdoors at three meters and also to protect against sleep interference and hearing damage. Since hearing damage effects are dependent upon sound energy, they are best discussed in terms of $L_{eq}$ 24. EPA has identified an $L_{eq}$ 24* of 70 dB as protecting against hearing damage.

If one took an average of all the APTA noise level values ($L_{dn}$) for the residential categories the result would be about 6 dB below the FHWA $L_{dn}$ value for residences.

APTA design goals also appear to require somewhat lower noise levels (about 4 dB less) in the commercial and industrial categories and would even fall below the EPA criterion for these types of areas.

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*$L_{eq}$ is preferred to $L_{dn}$ for this purpose because $L_{dn}$ is weighted for nighttime noise and therefore emphasizes annoyance rather than providing an accurate indication of acoustical energy.

TABLE 3-10 COMPARISON OF EPA, APTA, AND FHWA GUIDELINE CRITERIA

| EPA | $L_{eq24}$ | TOTAL OUTDOOR $L_{dn}$ | APTA | $L_{eq24}$* | TOTAL* OUTDOOR $L_{dn}$ | FHWA | $L_{eq24}$ | TOTAL OUTDOOR $L_{dn}$ |
|---|---|---|---|---|---|---|---|---|
| QUIET AREAS LIMITED USE | - | - | QUIET AREAS | - | - | QUIET AREAS | 57 | 61 |
| | | | LOW DENSITY RESIDENTIAL | | | | | |
| | | | ONE-FAMILY | 53 | 57-59 | | | |
| | | | MULTI-FAMILY | 58 | 62-63 | | | |
| | | | COMMERCIAL | 63 | 67 | | | |
| | | | AVERAGE RESIDENTIAL | | | | | |
| RESIDENTIAL | 51 | 55 | ONE-FAMILY | 58 | 62-64 | RESIDENCES | 67 | 71 |
| | | | MULTI-FAMILY | 58 | 62-64 | | | |
| | | | COMMERCIAL | 63 | 67-68 | | | |
| | | | HIGH DENSITY RESIDENTIAL | | | | | |
| | | | ONE-FAMILY | 58 | 63-66 | | | |
| | | | MULTI-FAMILY | 63 | 67-69 | | | |
| | | | COMMERCIAL | 68 | 72-73 | | | |
| COMMERCIAL | 70 | NA | COMMERCIAL | 68 | NA | DEVELOPED LAND OTHER THAN ABOVE | 72 | 73 |
| INDUSTRIAL | 70 | NA | INDUSTRIAL/ HIGHWAY | 68 | NA | | | |

* $L_{eq24}$ and $L_{dn}$ values derived from APTA $L_A$(Max) criteria, based on MBTA Red Line parameters of 144 day, 30 evening, 39 night pass-bys; 2.8 cars/train; 27.9 meter cars; 14.7 m/sec.; at 15 meters from near track.

# 4. COMPOSITE RAIL SYSTEM

The Composite Rail System is a hypothetical rail transit system comprised of types of vehicles and track structures in the same proportions as they exist in six of the transit systems studied in the National Assessment. Sound level data for the in-car, in-station, and wayside environments of each of the six systems has been aggregated, providing an overview of the total U.S. urban rail environment. This survey includes the following information:

1. Average maximum pass-by levels, $L_A$(Max);
2. Distribution of $L_A$(Max) levels based on average sound levels for each track structure and vehicle type;
3. Equivalent sound levels, $L_{eq}$, $L_{dn}$, and Relative $L_{dn}$;
4. Comparison of sound level data with transit industry noise level goals for new systems; and
5. Amount of exposure to transit noise experienced by patrons and wayside community residents.

## 4.1 SYSTEM DESCRIPTION

The Composite Rail Transit System is comprised of the transit routes operated by the following six transit authorities included in this report:

1. Massachusetts Bay Transportation Authority (MBTA); Red Line, Blue Line, Orange Line.
2. Southeastern Pennsylvania Transportation Authority, (SEPTA); Market-Frankford Line, Broad Street Subway.
3. Port Authority Transit Company (PATCO); Lindenwold Line.
4. Cleveland Transit System (CTS), now part of the Greater Cleveland Regional Transit Authority (RTA); Airport Line.
5. Bay Area Rapid Transit System (BART).
6. Chicago Transit Authority (CTA); North-South Route, West-South Route, Evanston Service, Skokie Swift, Ravenswood Service, West-Northwest Route.

The New York City Transit Authority (NYCTA), including the Staten Island Rapid Transit Operating Authority (SIRT), is treated separately in this section. Due to the large size of the transit routes operated in New York, only two routes of the NYCTA, the IND-D and the IRT-#5, have been considered for parts of this analysis. These two routes are representative of most of the types of track structure and vehicles found on the New York systems. In addition, the wayside communities along these two lines represent a wide range of residential population densities.

The Composite Transit System operates nearly 393 km (244 mi) of right-of-way over varying types of track structures. The three most prevalent types are at-grade (24 percent), subway (23 percent) and elevated steel (22 percent). The remaining track structure breakdown is as follows: elevated concrete (10 percent), elevated embankment (9 percent), median strip (7 percent), open-cut (4 percent) and track on bridges (1 percent).

The combined right-of-way mileage in New York City is approximately 398 km (247 mi), with two structures predominating - subway (57 percent) and elevated steel (26 percent). The remaining mileage is distributed over at-grade (6 percent), open-cut (6 percent), elevated embankment (3 percent), and elevated concrete (2 percent) track.

More than half of the rail of the Composite System (59 percent) is welded -either continuous or field, with the remaining 41 percent jointed. In New York, the overwhelming majority of rail is jointed (98 percent), with only 2 percent (all located on SIRT property) field-welded.

Since the noise measurements were compiled in 1974, several component routes have undergone changes, in particular the MBTA, SEPTA and NYCTA systems. For a complete description see Appendices A, B and G, respectively.

## Stations

There are approximately 300 stations on the Composite Rail System. A small percentage (12 percent) have been acoustically treated, of which approximately half are on BART properties. For a description of these stations, see the individual system descriptions, Appendices A through F.

The two New York City authorities operate 485 stations, of which 22 are on the SIRT route. No sound treatments are normally included in the stations.

## Vehicles

The rail transit fleet operating over the Composite System numbers approximately 2500 vehicles. These have been combined into two categories: vehicles constructed prior to 1964 (64 percent), and vehicles constructed in 1964 or later (36 percent). Nearly all rail cars in the latter category (98 percent) have had some kind of acoustical treatment, ranging from air conditioning with sealed windows to thermal/acoustical insulation to increase the car-body transmission loss. For a more complete description of the use of acoustical treatments see Appendices A through F, in particular A (MBTA), C (PATCO), and E (BART).

NYCTA and SIRT operate approximately 6870 rail transit vehicles, of which 72 percent were constructed prior to 1964, and 28 percent in 1964 or later. Forty-seven percent of the cars in the latter category contain acoustical treatments, but only the newest rail vehicles (18 percent of the cars in this category) register a significant reduction in interior car noise levels.

## System Peculiarities

The types of track and types of roadbed construction in the Composite Rail System vary widely among transit authorities and among individual routes within a transit system. Table 4-1 shows the type of track structure, type of rail and the type of roadbed construction used by each operating authority.

## TABLE 4-1 COMPOSITE RAIL SYSTEM - TYPES OF STRUCTURES, RAIL AND ROADBED CONSTRUCTION

| OPERATING AUTHORITY | TRACK STRUCTURE | RAIL TYPE | ROADBED CONSTRUCTION |
|---|---|---|---|
| MBTA (Multiple Routes) | ELEVATED STEEL | Jointed, occassionally field welded | Wood ties and ballast |
| | AT-GRADE | Continuous welded rail | Concrete ties and ballast |
| | AT-GRADE | Jointed | Wood ties bolted onto open deck steel structure |
| | UNDERGROUND | Jointed occasionally field welded | Wood ties and ballast |
| | | Jointed | Wood ties and ballast |
| SEPTA (Multiple Routes) | ELEVATED STEEL | Jointed, occasionally field welded | Steel structure supports concrete sub-base on which wood ties and ballast are laid. |
| | UNDERGROUND | Jointed | Rail set on tie plates located on resilient pads on a concrete roadbed |
| | | | Rail set on wood ties embedded in concrete. |
| | | | Every fifth tie is a long tie. |
| PATCO | AT-GRADE | Continuous Welded Rail | Wood ties and ballast |
| | ELEVATED EMBANKMENT | | |
| | OPEN CUT | | |
| | ELEVATED CONCRETE | | Rail directly mounted to concrete base. |
| | BENJAMIN FRANKLIN BRIDGE | Jointed | Rail set on wood ties embedded in concrete. |
| | UNDERGROUND | | Everyfifth tie is a long tie. |
| | | Continuous Welded Rail | Rail directly mounted to concrete base using compression clips. |
| RTA (CTS) | AT-GRADE | Field Welded Rail | Wood ties and ballast |
| | ELEVATED EMBANKMENT | | |
| | OPEN CUT | | |
| | UNDERGROUND | | |
| BART (Multiple Routes) | AT-GRADE | Continuous Welded Rail | Wood ties and ballast |
| | ELEVATED CONCRETE | | Rail directly mounted to concrete trackbed using resilient rail fasteners. |
| | UNDERGROUND | | |
| CTA (Multiple Routes) | AT-GRADE | Welded ([illegible]), Jointed (66%) | Wood ties and ballast |
| | MEDIAN STRIP | Welded | Concrete ties and ballast |
| | | Welded, occasionally jointed | Wood ties and ballast |
| | ELEVATED STEEL | Jointed | Wood ties bolted onto open deck steel structure |
| | ELEVATED CONCRETE | | Wood ties and ballast on concrete base |
| | OPEN CUT | | Wood ties and ballast |
| | ELEVATED EMBANKMENT | Welded (44%), Jointed (56%) | |
| | UNDERGROUND | Welded (96%), Jointed (4%) | Rail set on tie plates directly mounted to concrete base |
| | | | Wood ties embedded in concrete |
| | | | Concrete ties and ballast (All welded) |
| NYCTA (Multiple Routes) AND SIRT | AT-GRADE | Jointed[1] | Wood ties and ballast |
| | ELEVATED EMBANKMENT | | |
| | OPEN CUT | | |
| | ELEVATED CONCRETE (NYCTA only) | | Wood ties and ballast on concrete base |
| | ELEVATED STEEL (NYCTA only) | | Wood ties bolted onto open deck steel structure. |
| | UNDERGROUND | | Wood ties and ballast |
| | | | Concrete with wood and invert |
| | | | Concrete direct mount |

[1] Some of the track (24%) on the SIRT Route is welded, but only comorises 2% of the right-of-way miles in New York City

From the above table it can be seen that only at-grade and underground track are common to all operating authorities. The roadbed construction on underground track is the most varied, with several types of roadbed represented. Other interesting variations occur on elevated steel and elevated concrete track. Note that the roadbed of the elevated steel track on SEPTA is ballasted, unlike the elevated steel structures in all other systems. Similarly, the track on elevated concrete sections on BART and PATCO is directly fastened to a concrete base, while the elevated concrete structures on CTA and NYCTA are ballasted.

There are other differences among routes and authorities which are not apparent from the table. In several systems, other transportation modes are adjacent to the transit operations. In Cleveland, for example, the Airport Line runs parallel to both the Penn Central and Norfolk and Western rights-of-way. For a more complete discussion, see the individual system descriptions in Appendices A through F.

## 4.2 IN-CAR NOISE

### 4.2.1 Plateau Sound Levels

In-car plateau sound levels, $L_A$(Max), on the Composite System range from 70 to 105 dBA, as shown in Figure 4-1. The distribution of in-car sound levels on the NYCTA is similar in shape to that of the Composite of the other six systems, but noise levels are approximately 10 dBA higher.

As shown in Table 4-2, the pattern of in-car $L_A$(Max) levels is related to types of track structure and types of car. In-car levels for a given transit car on underground track are universally higher than on any other type track; however, the pattern of in-car levels on aboveground track varies from system to system. Noise levels are generally considerably lower in acoustically treated cars on the MBTA and NYCTA than on non-treated cars. On the CTA, however, no reduction in noise levels is evident on the acoustically treated cars.

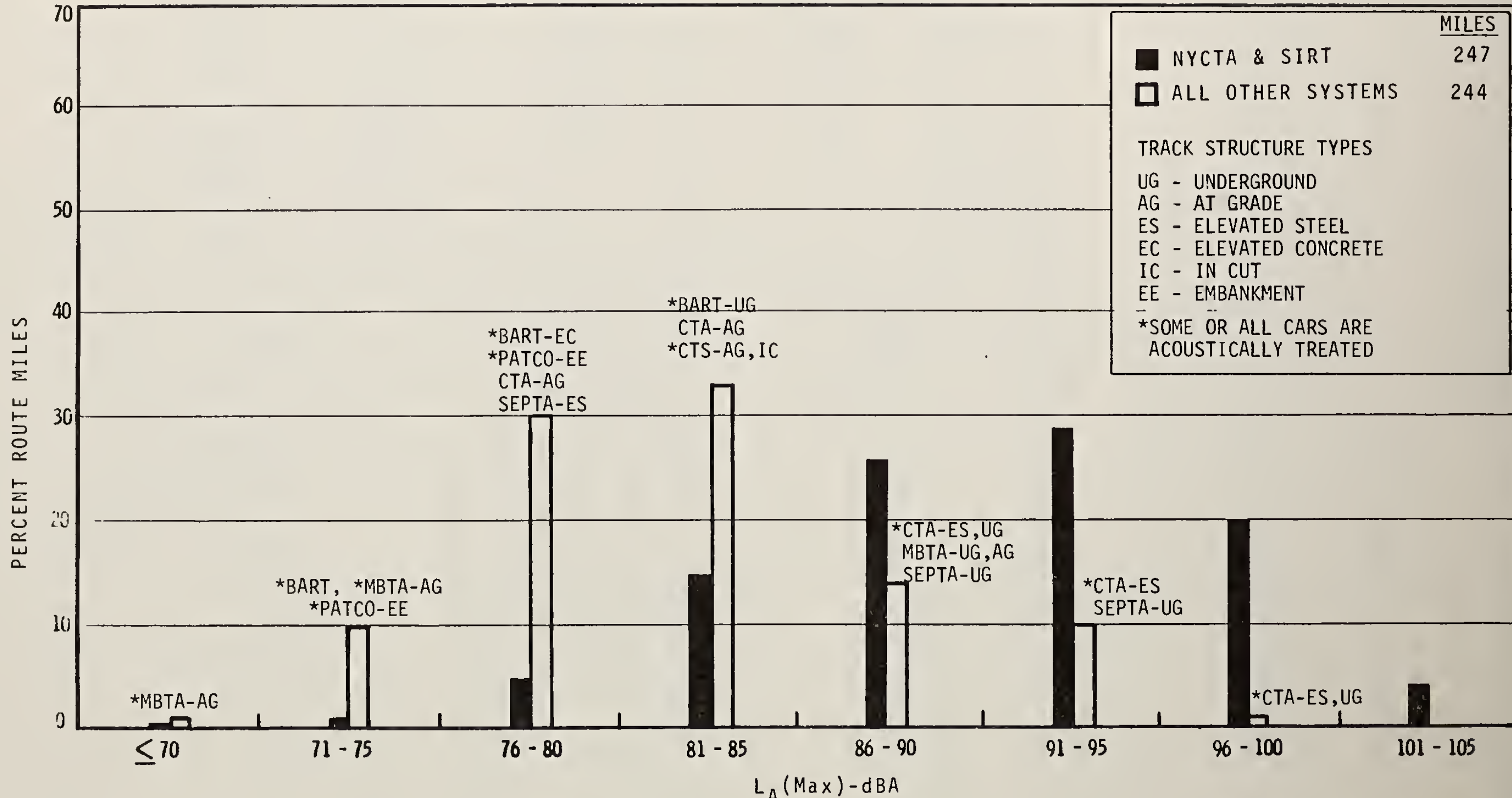


FIGURE 4-1 COMPOSITE SYSTEM, DISTRIBUTION OF IN-CAR PLATEAU NOISE LEVELS

# TABLE 4-2 IN-CAR $L_A$(MAX) INTERSYSTEM COMPARISON

TRACK STRUCTURE

| SYSTEM | Underground | Elevated Steel | Elevated Concrete | At-Grade (Jointed) | At-Grade (Welded) | In-cut | Elevated Embankment | Bridge/ Crossover |
|---|---|---|---|---|---|---|---|---|
| MBTA | 91[1], 87[2], $\underline{78}$[3]<br>(2.0) (7.1) (4.8) | 82[2], $\underline{75}$[3]<br>(7.6)(.2) | | 87[1], 80[2]<br>(4.0) (2.5) | $\underline{72}$[3]<br>(6.0) | | | 83[2], $\underline{75}$[3]<br>(0.4) (0.4) |
| SEPTA | 91[4], 87[5], 85[6]<br>(9.8) (3.8) (3.8) | 80[5], 78[6]<br>(8.3) (8.3) | | 89[4], 80[5], 74[6]<br>(0.4) (0.6) (0.6) | | | | |
| PATCO | $\underline{79}$[7], $\underline{78}$[8]<br>(2.5) (2.5) | | *<br>(0.9) | | | *<br>(1.0) | $\underline{74}$[7], $\underline{75}$[8]<br>(8.3) (8.3) | $\underline{73}$[7], $\underline{72}$[8]<br>(1.5) (1.5) |
| RTA | *<br>(1.0) | | | | 84[9], 84[10]<br>(8.5) (8.5) | 83[9], 84[10]<br>(8.8) (8.8) | 84[9], 84[10]<br>(0.7) (0.7) | |
| BART | $\underline{84}$<br>(19.7) | | $\underline{78}$<br>(23.0) | | $\underline{75}$<br>(27.7) | | | |
| CTA | 90[11]<br>(9.6) | 88[11], $\underline{91}$[12]<br>(27.1) (8.6) | *<br>(0.6) (0.6) | 80[11]<br>(5.5) | 82[11], $\underline{85}$[12]<br>(11.7) (8.9) | 84[11]<br>(1.6) | 84[11], $\underline{85}$[12]<br>(9.6) (2.5) | |
| NYCTA<br>(IND.D and IRT-#S) | 98[13], 99[14], $\underline{82}$[15]<br>(12.4) (18.9) (18.9) | 91[13], 88[14], $\underline{76}$[15]<br>(3.5) (2.0) (0.8) | | 92[13], 93[14], $\underline{81}$[15]<br>(2.3) (3.0) (3.0) | | 94[13], 92[14], $\underline{78}$[15]<br>(1.7) (2.3) (2.3) | 92[13], 93[14], $\underline{81}$[15]<br>(2.3) (3.0) (3.5) | |

NOTE
- Underlined Noise Levels denote acoustically treated cars.
- Numbers in parenthesis are route miles characterized by these sound levels

* No noise measurement for this type track structure
(see also footnotes below)

## NOTES FOR TABLE 4-2

1. MBTA Blue Line Cars
2. MBTA Orange Line Cars & Red Line "Bluebirds"
3. MBTA Red Line "Silverbirds"
4. SEPTA Broad Street Subway Cars
5. SEPTA Market-Frankford Line Single Cars
6. SEPTA Market-Frankford Line Double Cars
7. PATCO Single Cars
8. PATCO Double Cars
9. RTA St. Louis Cars
10. RTA Pullman Standard Cars
11. CTA 6000 Series Cars (CTA mileages are for
12. CTA 2200 Series Cars noisiest car on route)
13. NYCTA - IRT Cars
14. NYCTA - Non-R-44, Non-IRT Cars
15. NYCTA - R-44 Cars

It should be noted that factors such as train speed, car and rail conditions, and track geometry could also contribute to variations in the in-car $L_A$(Max) levels. The following section describes the distribution of route mileage by in-car $L_A$(Max) for the Composite System, followed by a description of the New York System. The types of track structure accounting for most of the Composite mileage at each sound level interval is noted, as shown in Figure 4-1.

The highest in-car $L_A$(Max) levels for the Composite System are in the interval from 96 to 100 dBA. This represents sections of elevated steel and underground track on the CTA.

The route mileage characterized by in-car levels between 86 and 95 dBA represents elevated steel track on the CTA and underground track on SEPTA and the CTA, as well as underground and at-grade track on the MBTA. These sections comprise approximately 75 percent of the Composite route mileage with in-car $L_A$(Max) levels in the 86 to 95 dBA interval.

With the exception of cars operating on route mileage on elevated steel track on the CTA, in-car levels above 85 dBA are found on cars which have no acoustical treatment.*

Route mileage over which in-car levels of 81 to 85 dBA are experienced is found on each of the six component systems of the Composite Rail Transit System. The largest percentages of mileage having in-car levels in this range are on underground track on BART, at-grade track on CTA and RTA, and in-cut track on RTA. Acoustically treated cars are operated on the majority of these routes.

In-car $L_A$(Max) levels of 76 to 80 dBA are found in acoustically treated cars on elevated concrete track on BART, and on embankment track on PATCO. Mileage in the 76 to 80 dBA interval also represents non-acoustically treated cars on at-grade track (welded track) on the CTA, and elevated steel track on SEPTA.

*RTA Pullman cars with air conditioning are also in this range.

In-car levels of 71 to 75 dBA are found on at-grade track on BART and MBTA, and on embankment track on PATCO. The lowest in-car $L_A$(Max) levels, from 66 to 70 dBA, represent at-grade track on the MBTA. Cars operated on all of the above route mileage with in-car levels of less than 76 dBA are acoustically treated, and all of the track is welded.

On the New York system, the highest in-car $L_A$(Max) levels, 101 to 105 dBA, are experienced on underground track. Although no breakdown of route mileage by type of track was available for the entire New York system, some inferences about the distribution may be drawn from the averages for each type of track and type of car given in Table 4-2.

In-Car $L_A$(Max) - Track Structure Averages

Figure 4-2 is a distribution of average maximum in-car sound levels. This distribution has been derived from the average $L_A$(Max) level for each type of track structure and type of car on each rail system. In comparing Figure 4-1 with Figure 4-2, one notices that the averaging procedure has eliminated the extreme values. A simplified distribution of this type, in conjunction with the route mileages for each type of track as given in Table 4-2, is useful for making assessments related to type of track and type of car, such as estimates of noise abatement costs. Acoustically treated cars clearly dominate the lower in-car noise levels. Conversely, non-acoustically treated vehicles account for most of the route mileage with in-car levels above 85 dBA. (Note: the distribution in Figure 4-2 reflects the route mileage served by each type of transit car on a system, except in the case of the CTA, where only the noisiest type of car is accounted for.)

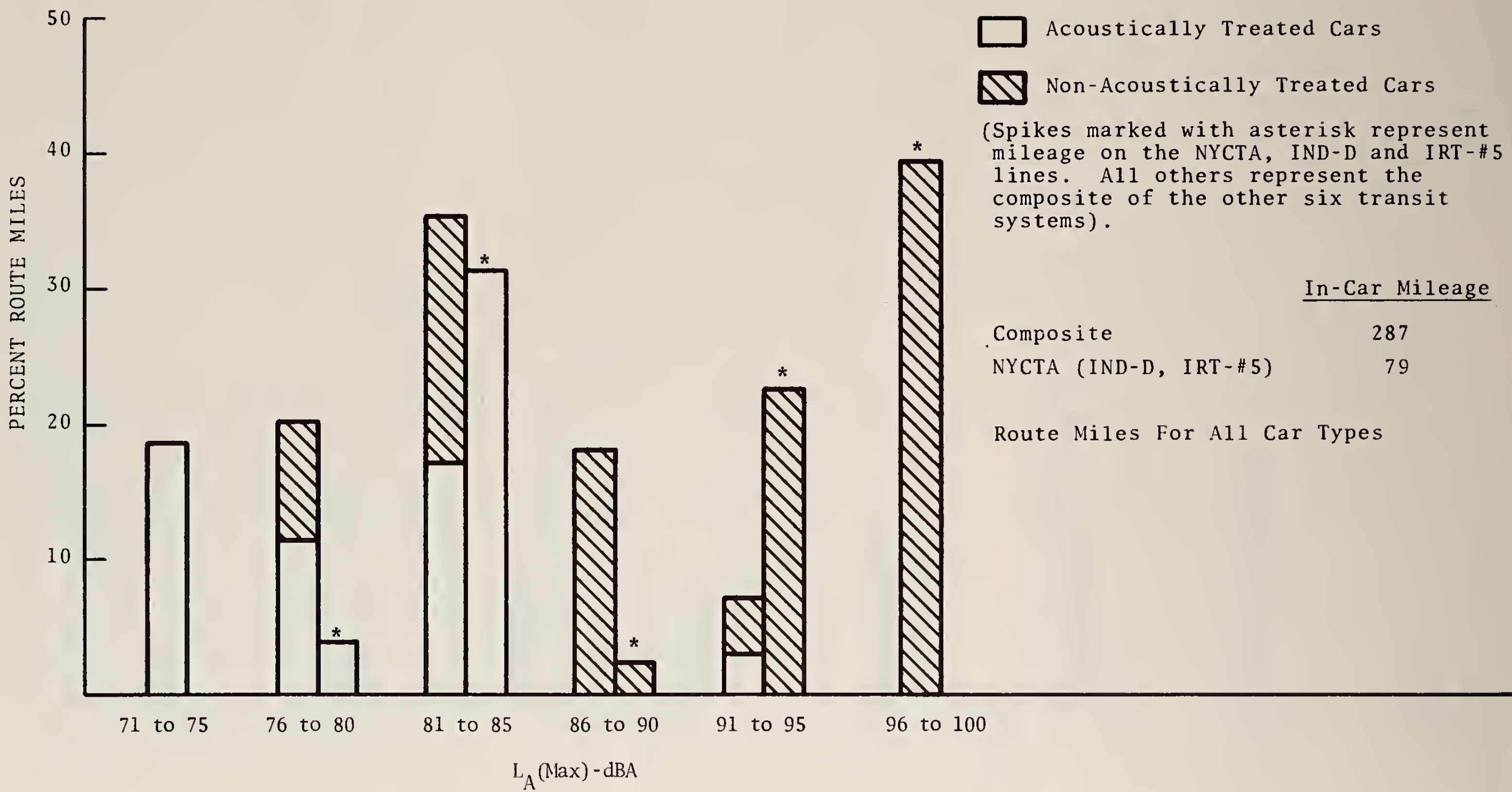


FIGURE 4-2 COMPOSITE RAIL SYSTEM, IN-CAR PLATEAU SOUND LEVELS, TRACK STRUCTURE AND CAR TYPE AVERAGES

### 4.2.2 Equivalent Sound Levels

In-car equivalent sound levels, $L_{eq}$, for the Composite Rail System are shown in Figure 4-3. Only route mileage of the two representative lines of the New York System, about 4 percent, is characterized by in-car $L_{eq}$ of over 100 dBA. Fifty-seven percent of the representative NYCTA route mileage, and only six percent of the Composite System mileage, are characterized by in-car $L_{eq}$ of 91 to 100 dBA. Fifty-one percent of the Composite, and only 17 percent of the NYCTA route mileage, have in-car $L_{eq}$ values of less than or equal to 80 dBA.

### 4.2.3 Noise Exposure

Exposure of transit riders on the Composite System to in-car noise is expressed in Figure 4-4 as a distribution of people-hours (ridership weighted by trip time) over in-car $L_{eq}$ levels. The methods used to derive these measures are explained in detail in Section 2 and Appendix H. Note that for this analysis only the IND-D and IRT-#5 lines of NYCTA have been analyzed.

Half of the in-car exposure on the Composite System is to levels above 80 dBA, with very little exposure to levels above 95 dBA. On the two lines representing NYCTA, over half of the in-car exposure is to equivalent levels of over 90 dBA.

### 4.2.4 Sound Level Comparison with APTA Goals

In Figure 4-5, in-car $L_A$(Max) levels have been compared with the American Public Transit Association (APTA) goals for new systems. As explained previously, the APTA goals for in-car sound levels vary by type of track, which explains the difference between this figure and the distribution of $L_A$(Max) shown in Figure 4-1. Only two routes of the NYCTA, the IND-D and the IRT-#5, have been analyzed. It can be seen that most (84 percent) of the Composite has in-car $L_A$(Max) levels which are one to fifteen dBA above the APTA goals for new systems. The five percent of the route mileage with in-car levels below the APTA goals represents

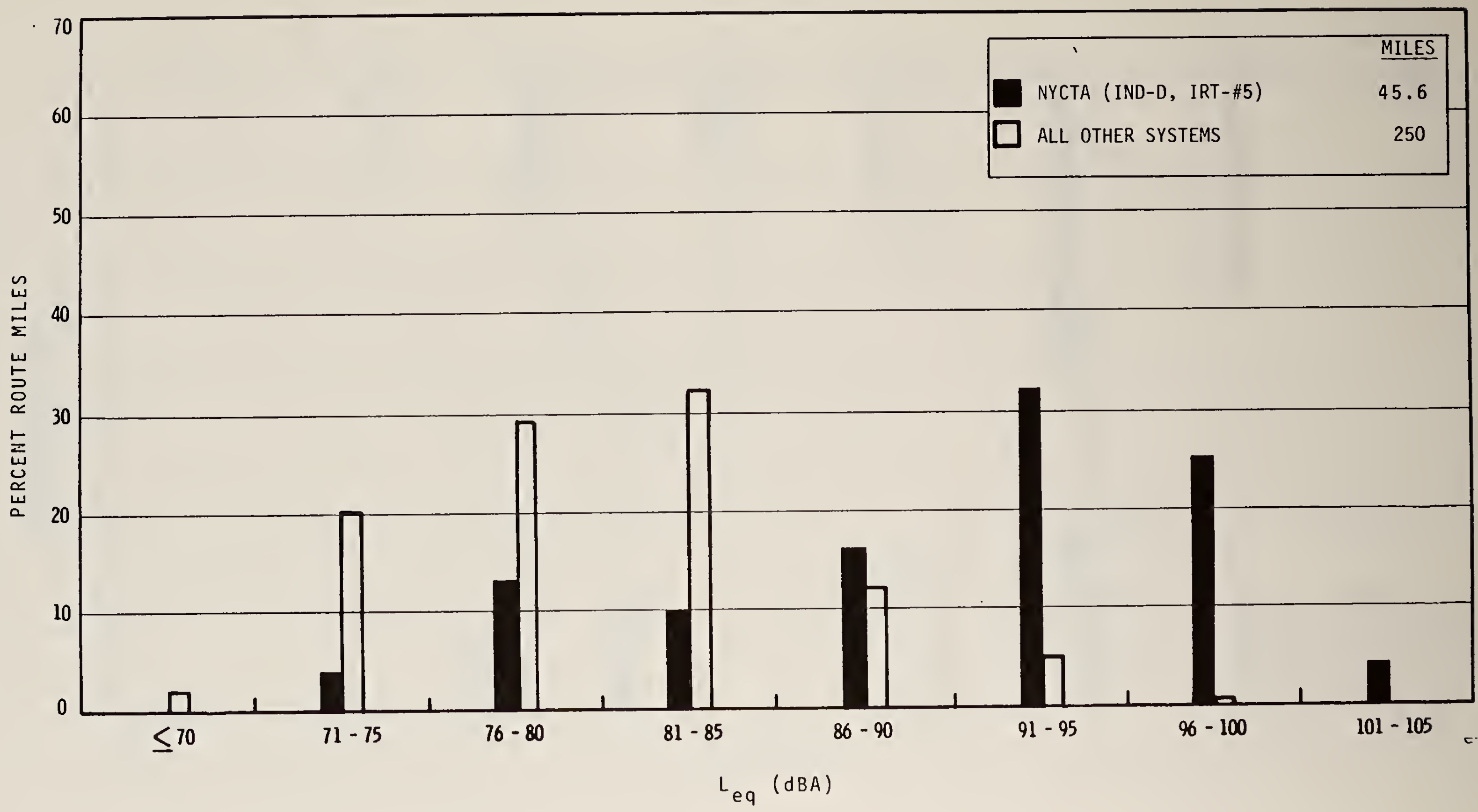


FIGURE 4-3 COMPOSITE SYSTEM, IN-CAR EQUIVALENT SOUND LEVELS

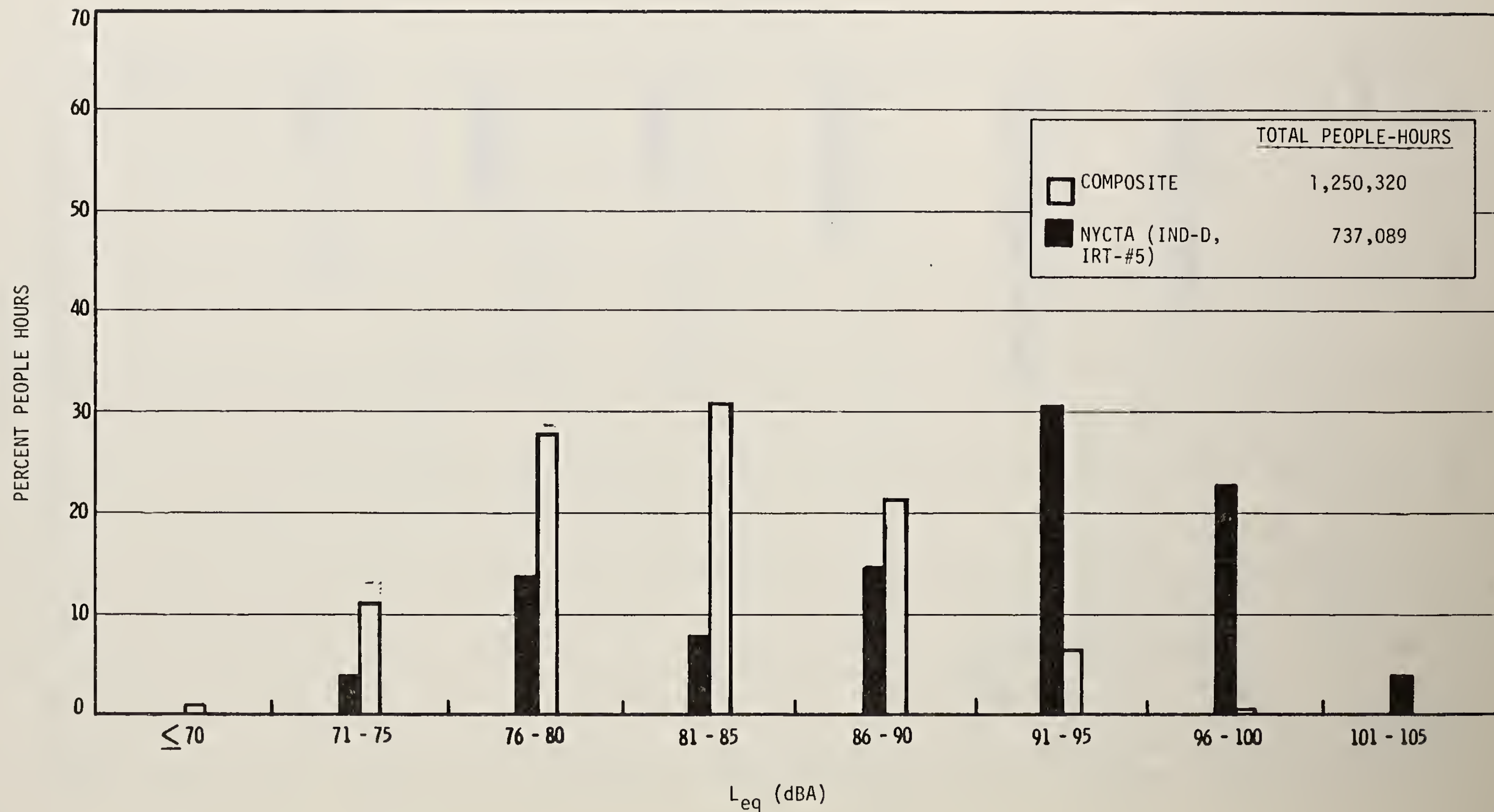


FIGURE 4-4 COMPOSITE SYSTEM, IN-CAR NOISE EXPOSURE

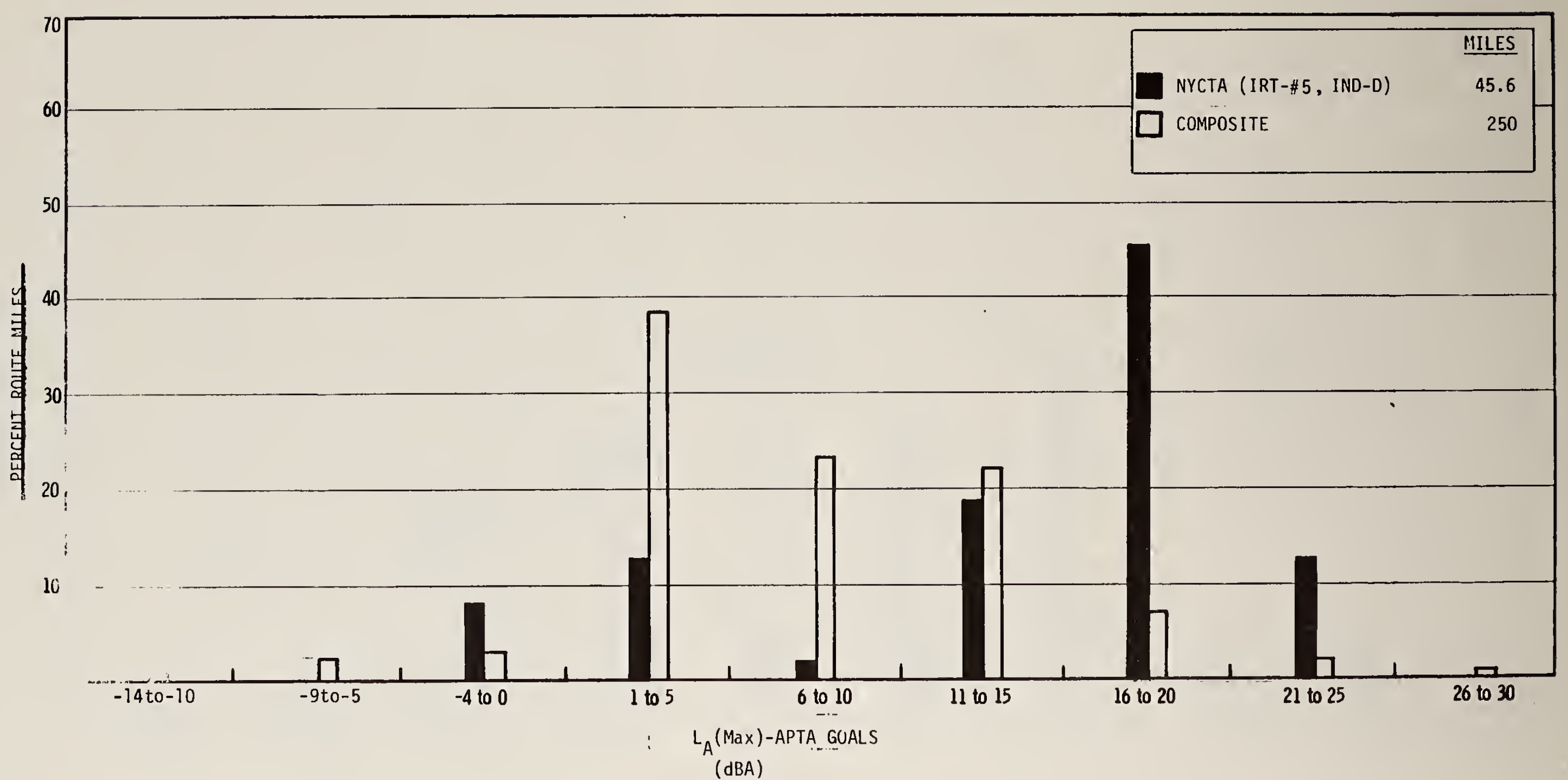


FIGURE 4-5 COMPOSITE SYSTEM, IN-CAR NOISE GOAL COMPARISON

primarily acoustically treated cars on underground track on PATCO and MBTA. Route mileage on the two representative lines of NYCTA with in-car $L_A$(Max) at or below the APTA goals is in acoustically treated cars underground or in cuttings. In-car sound levels of more than 15 dBA above the APTA goals are found primarily in non-acoustically treated cars on elevated steel track on the CTA, and on elevated, underground, and embankment trackage on the representative lines of NYCTA.

## 4.3 STATION NOISE

### 4.3.1 Maximum Sound Levels

Average maximum sound levels, $L_A$(Max), on the eight systems studied range from 70 to 115 dBA, as shown in Figure 4-6. Except for one CTA underground station, all the stations with $L_A$(Max) above 100 dBA are underground stations on the NYCTA. Eighty-five percent of the New York stations are characterized by $L_A$(Max) levels above 90 dBA. In contrast, eighty-five percent of stations on the Composite System have $L_A$(Max) levels at or below 90 dBA.

There is a distinct relationship between station $L_A$(Max) levels and type of track, as shown in Table 4-3. The highest $L_A$(Max) levels for each system studied occur in underground stations. An exception to this pattern is underground stations on BART, where acoustical treatment has reduced maximum sound levels below those in stations on elevated concrete track. As displayed in Figure 4-6, underground stations and those on elevated track account for most of the stations in each of the $L_A$(Max) intervals from 86 to 110 dBA.

$L_A$(Max) levels in stations on other types of track structure are primarily in the range of 70 to 86 dBA, although higher levels exist occasionally.

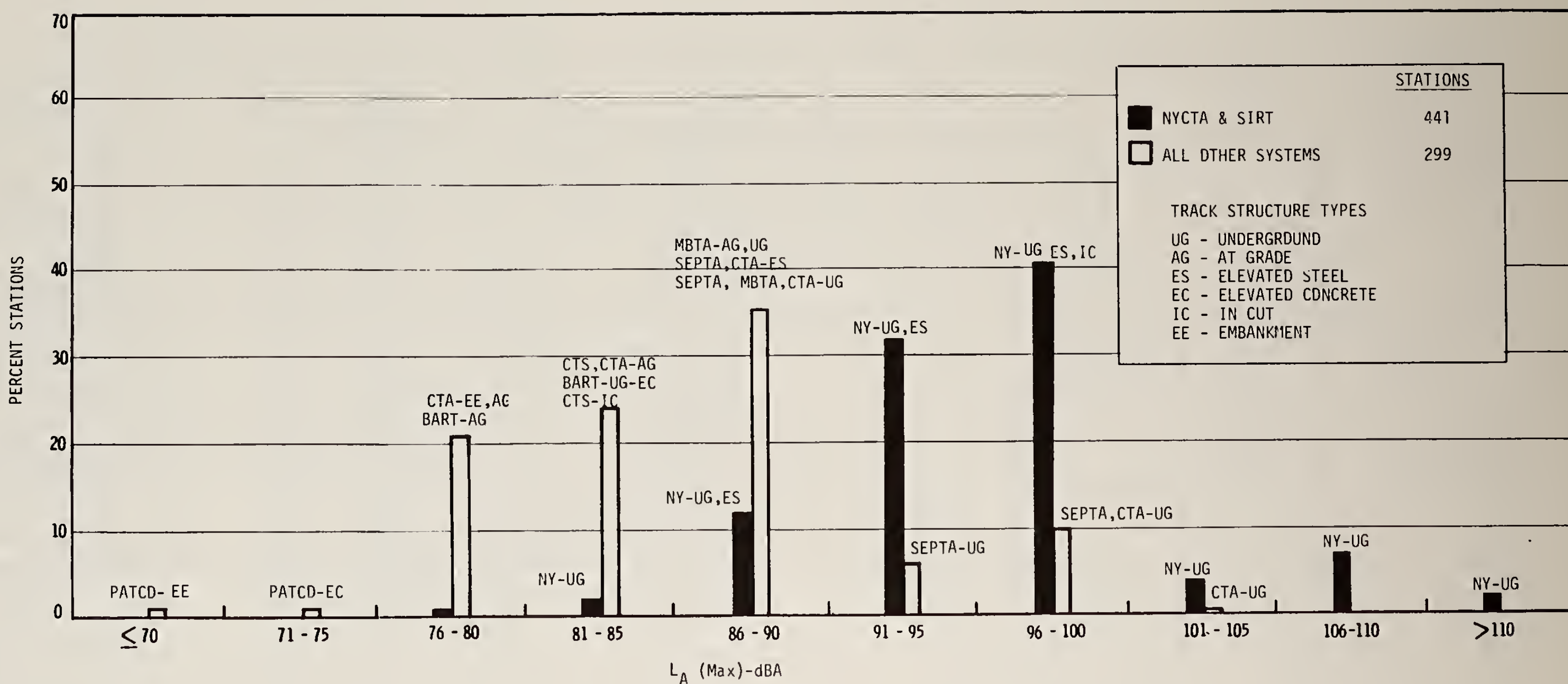


FIGURE 4-6 COMPOSITE SYSTEM, IN-STATION MAXIMUM NOISE LEVELS

TABLE 4-3 STATION NOISE LEVEL INTERSYSTEM COMPARISON

| AVERAGE $L_A(Max)$ - dBA (NO. OF STATIONS) | TRACK STRUCTURE | | | | | | |
|---|---|---|---|---|---|---|---|
| | UNDERGROUND | ELEVATED STEEL | ELEVATED CONCRETE | AT-GRADE JOINTED | AT-GRADE WELDED | IN-CUT | EMBANKMENT |
| MBTA | 89 (19) | 82 (12) | | 88 (10) | 85 (3) | | |
| SEPTA | 91 (34) | 86 (15) | | 84 (3) | | | |
| PATCO | 88 (6) | | 74 (2) | | | 80 (1) | 70 (3) |
| RTA | 85 (2) | | | | 83 (7) | 82 (7) | 83 (2) |
| BART | 81 (13) | | 82 (11) | | 76 (9) | | |
| CTA | 97 (19) | 86 (68) | 88 (1) | 76 (11) | 76 (22) | | 80 (22) |
| NYCTA & SIRT | 105 (267) | 93 (144) | 91 (15) | 91 (21) | | 95 (24) | 97 (14) |

In addition to the BART stations already mentioned, acoustical treatment also exists in aboveground stations of PATCO, and some stations of RTA. These stations appear to have slightly lower $L_A$(Max) levels than would be expected if no acoustical treatment had been applied. The NYCTA performed a controlled experiment in which acoustical treatment reduced sound levels from pass-through trains in an underground station by two to seven dBA.

In-station noise levels on the two New York systems were found to be five dBA lower for new model trains than for the older trains in both underground and aboveground stations. No differences in noise level due to car type were reported on the other six systems. The only reported differences in station noise levels due to the length of train were in CTA underground stations, where four- or eight-car trains produced noise levels 10-15 dBA higher than two-car trains.

### 4.3.2 Equivalent Sound Levels

Equivalent sound levels in stations on the Composite Rail System were measured for half hour periods, or derived from $L_A$(Max) levels, as explained in Appendix I. Because of the size of the NYCTA, $L_{eq}$ levels were derived only for stations of the IRT-#5 and the IND-D lines.

The distribution shown in Figure 4-7 resembles the distribution of $L_A$(Max) levels, with variations due to differences in headway times and categorization of the noise levels. Over 60 percent of the $L_{eq}$ levels on stations of the Composite System are less than 76 dBA. The highest levels are in the 91 to 95 dBA interval. $L_{eq}$ levels on the two representative lines of New York range from 71 to 100 dBA. Sixty percent of the $L_{eq}$ levels at stations on these two lines are above 85 dBA.

### 4.3.3 Noise Exposure

Figure 4-8 illustrates the distribution of patronage exposed to station $L_{eq}$ values. The patronage on the Composite System is fairly evenly distributed among the sound level categories. The patronage exposed to $L_{eq}$ levels above 85 dBA are on the SEPTA and

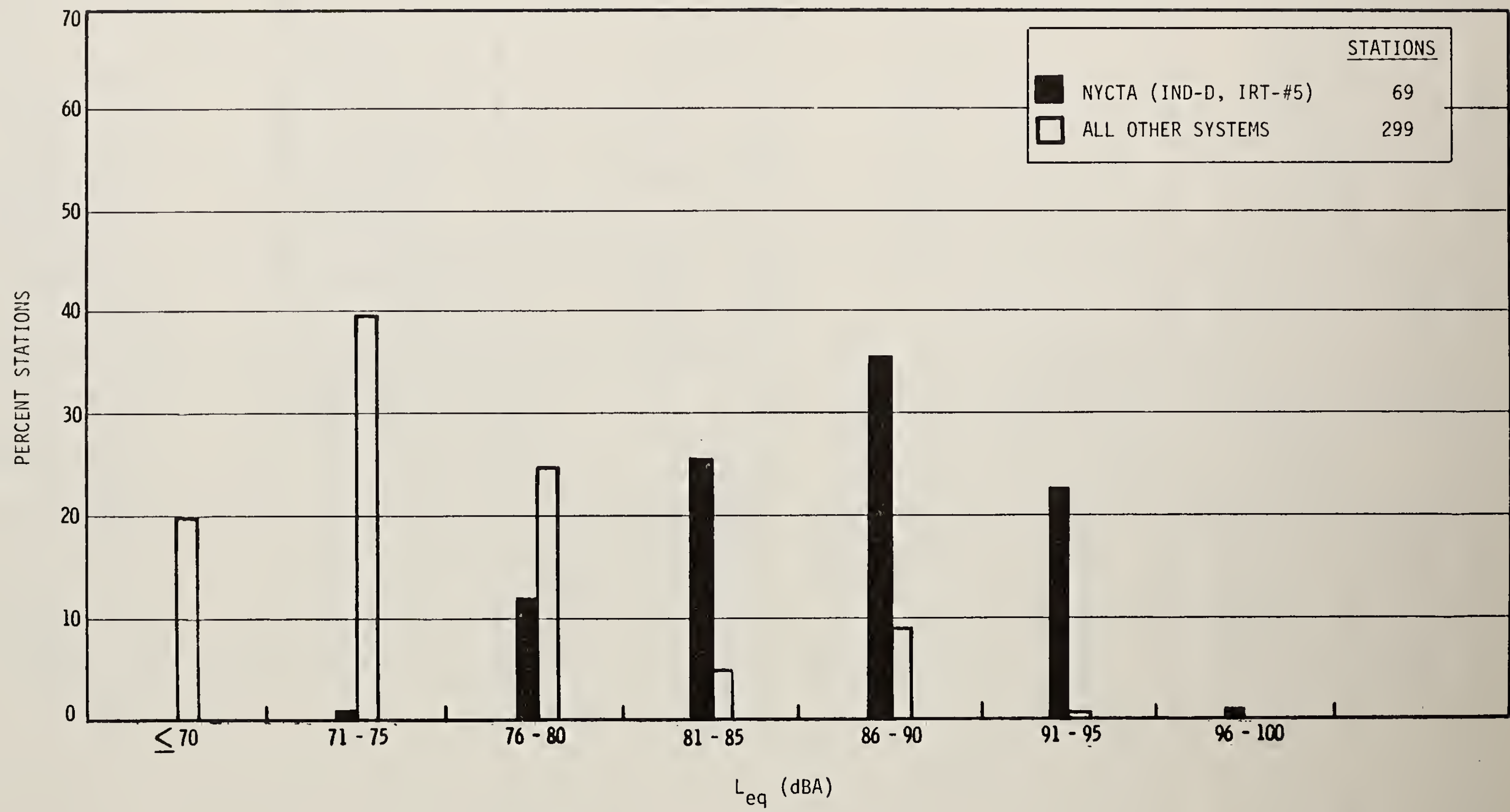


FIGURE 4-7 COMPOSITE SYSTEM, IN-STATION EQUIVALENT NOISE LEVELS

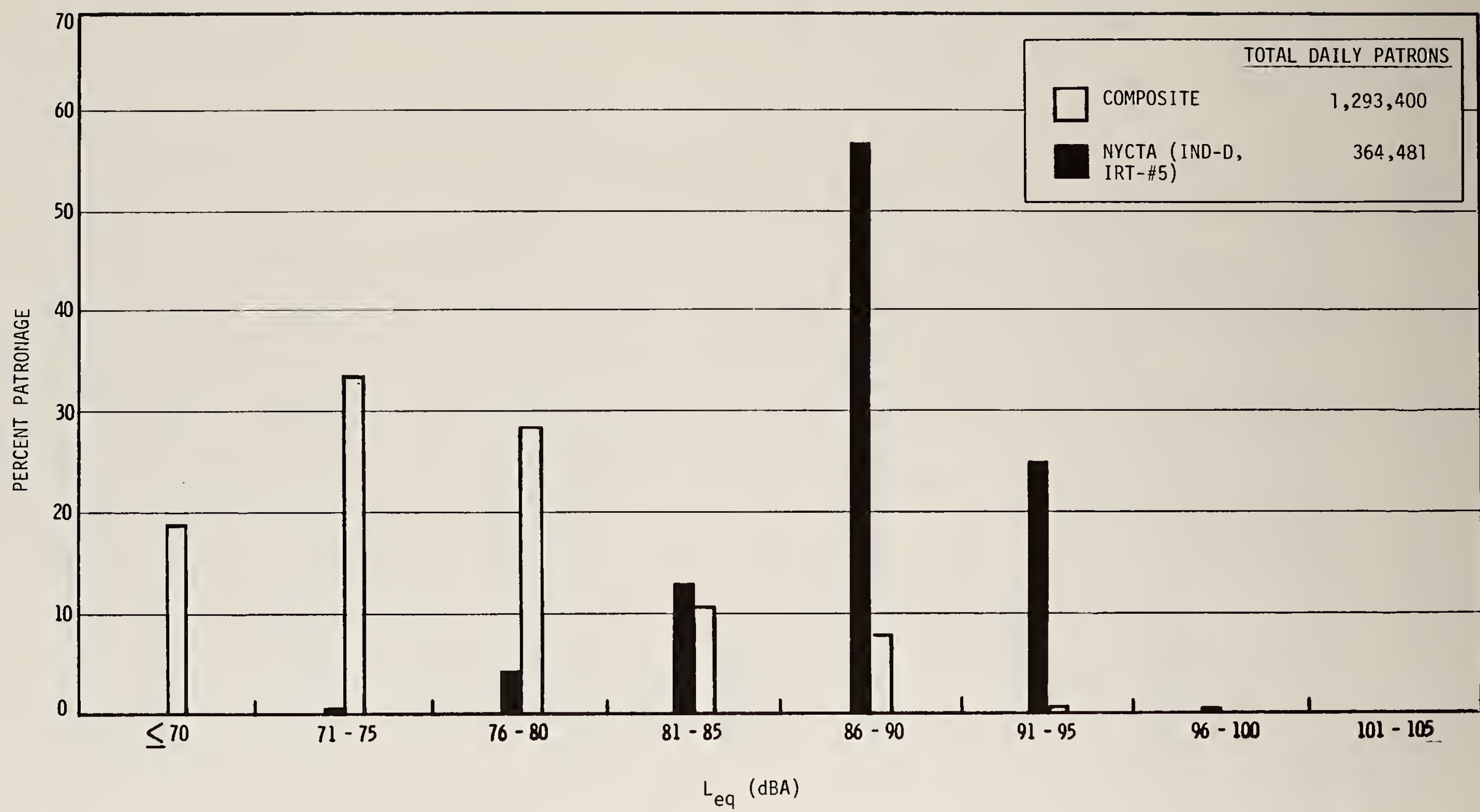


FIGURE 4-8 COMPOSITE SYSTEM, IN-STATION NOISE EXPOSURE

CTA systems. Of the patronage experiencing $L_{eq}$ levels at or below 70 dBA, over half are on BART, with smaller amounts on the CTA, PATCO, and MBTA.

The patronage distribution of the two representative lines from New York is concentrated in the 86 to 90 dBA interval, representing underground stations, principally those in Manhattan.

### 4.3.4 Comparison with APTA Guidelines

Figure 4-9 is a comparison of station $L_A$(Max) levels with the American Public Transit Association (APTA) goals for new stations (The APTA goals are outlined in Section 3). All of the stations on the New York systems are characterized by $L_A$(Max) levels of at least 6 dBA above the APTA goals. For the six systems excluding New York, 15 percent of the stations have $L_A$(Max) levels at or below the APTA goals. These include: at-grade and underground stations on BART and CTA; underground, embankment, and in-cut stations on CTA; and one in-cut station on PATCO. The remainder of the goal comparison is generally represented by station types which are distributed as in Figure 4-5.

## 4.4 WAYSIDE NOISE

### 4.4.1 Maximum Sound Levels - $L_A$(Max)

The measured average maximum sound levels resulting from train pass-bys, $L_A$(Max), have been extrapolated to characterize pass-by levels experienced in all sections of the wayside community for the Composite Rail System. These levels range from 74 to 101 dBA.

The above extrapolations have been based primarily on type of track structure and, in the case of the CTA (where such data were provided), adjusted for the average train speed on each line. For purposes of comparison, the maximum A-weighted pass-by sound levels have been normalized to 15 meters (50 feet) from the near track center-line. Residential areas in the wayside community have been identified, and all other areas classified as non-residential.

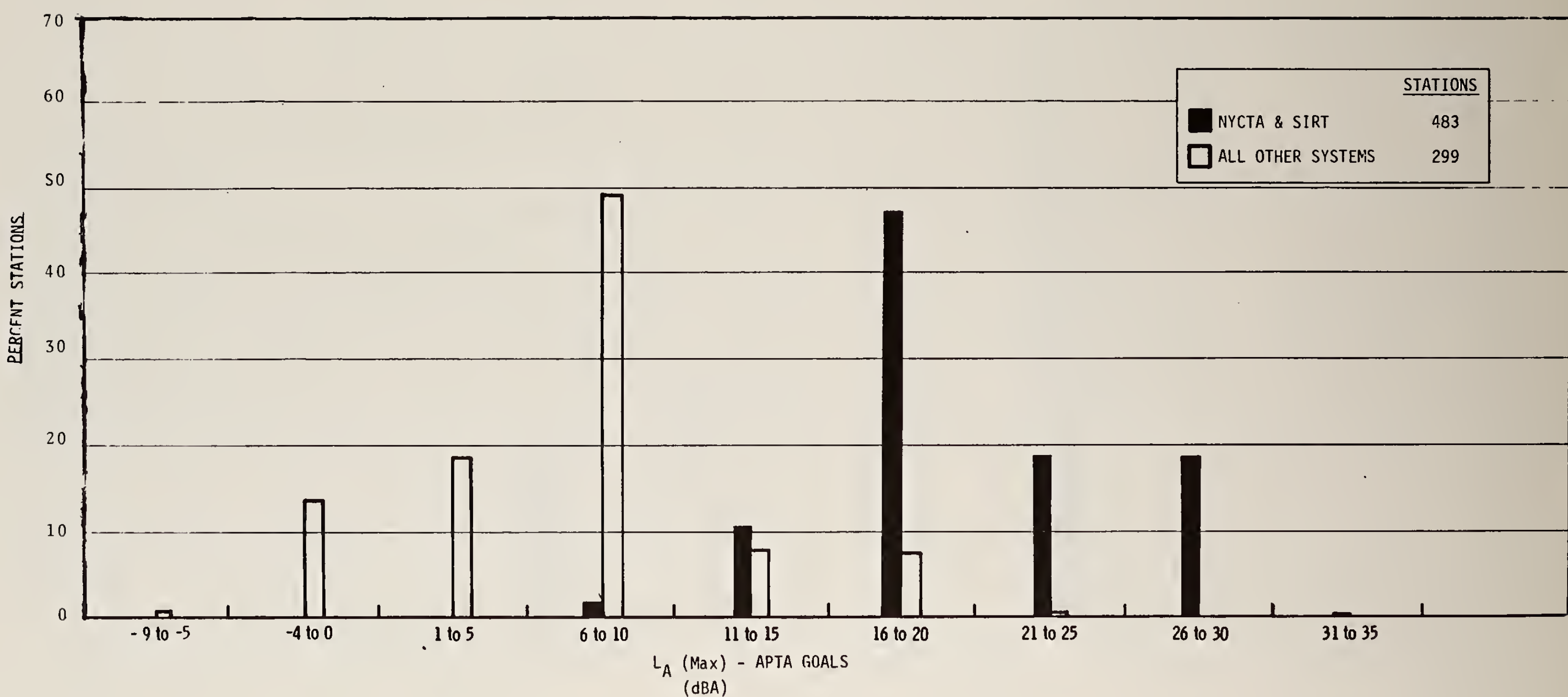


FIGURE 4-9 COMPOSITE SYSTEM, IN-STATION NOISE GOAL COMPARISON

The large size of the NYCTA and SIRT systems necessitated the assignment of one average $L_A$(Max) level to each type of track structure. These levels range from 76 to 92 dBA. It is important to note that an observer of any particular segment may experience levels which vary by as much as ten dBA from the system-wide averages.

Figures 4-10 and 4-11 illustrate the distribution of residential and non-residential mileage by $L_A$(Max) level. More than 62 percent of the wayside community of both the NYCTA and SIRT is residential, as compared to only 29 percent for the Composite System.

Examining each figure, one finds that approximately 55 percent of the composite system wayside experiences $L_A$(Max) levels of less than or equal to 90 dBA, whereas, in the case of the two New York City authorities, approximately 42 percent of both the residential and non-residential mileage experiences these $L_A$(Max) levels. A major reason for this difference is that nearly 58 percent of the NYCTA and SIRT aboveground right-of-way is comprised of elevated steel trackage as compared to 28 percent for the Composite Rail System.

Seventy-eight percent of the wayside mileage on the Composite Rail Transit System that experiences $L_A$(Max) levels in excess of 95 dBA abuts CTA elevated steel track. The remaining mileage (22 percent) is adjacent to RTA at-grade track.

In making estimates of noise abatement costs it is useful to represent sections of each type of track structure by an average sound level. Table 4-4 shows the average $L_A$(Max) levels by type of track structure for each transit authority. Figure 4-12 depicts the amount of wayside mileage at each sound level.

There is a positive correlation between wayside $L_A$(Max) levels and type of track structure, train speed, type of rail (welded or jointed), and conditions of wheel/rail (although the latter was not documented at the time of the noise measurements). Other factors, such as roadbed construction, also have a bearing on the overall pass-by level. Examining the composite system, one can observe some

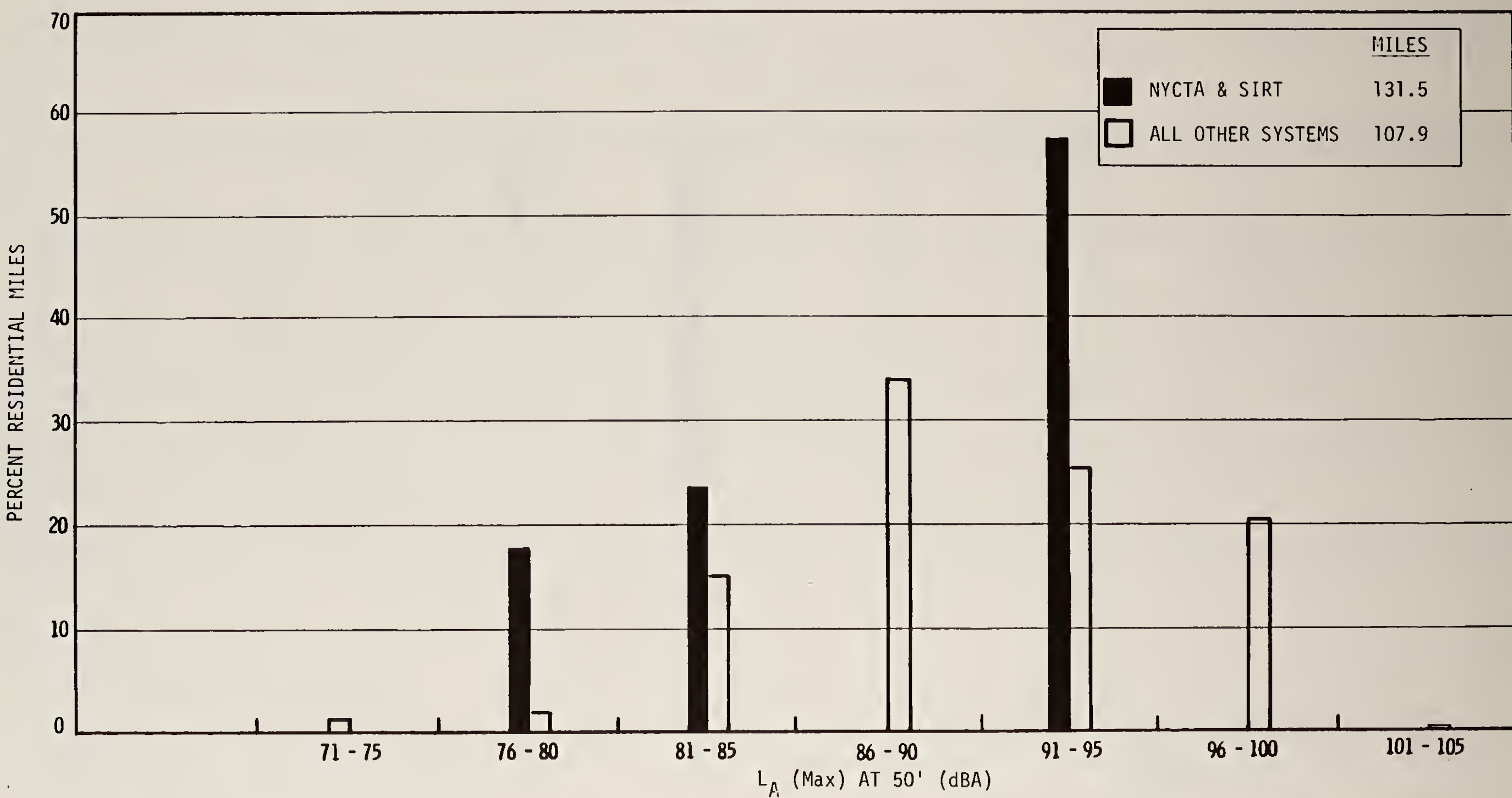


FIGURE 4-10 COMPOSITE SYSTEM, DISTRIBUTION OF RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

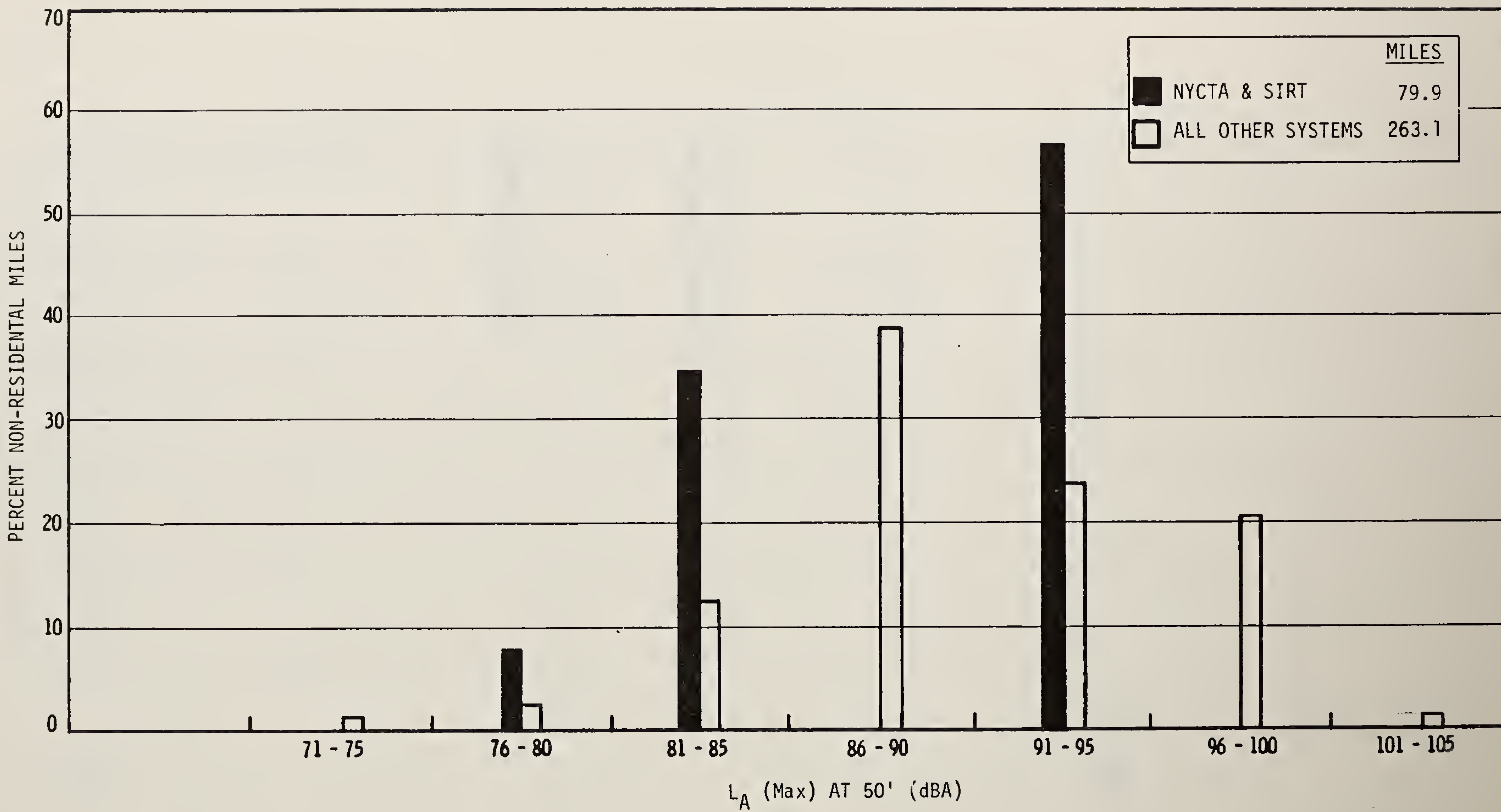


FIGURE 4-11 COMPOSITE SYSTEM, DISTRIBUTION OF NON-RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

# TABLE 4-4 WAYSIDE NOISE LEVEL INTERSYSTEM COMPARISON

| $L_A$ (Max) AT 50' FROM NEAR TRACK ℄ (dBA) (ROUTE MILEAGE) | TRACK STRUCTURE | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | MEDIAN STRIP | ELEVATED STEEL | ELEVATED CONCRETE | AT-GRADE JOINTED | AT-GRADE WELDED | IN-CUT | ELEVATED EMBANKMENT (JOINTED) | BRIDGE/ CROSSOVER | ELEVATED EMBANKMENT (WELDED) |
| MBTA | | 92[1,2,3] (16.4) | | 85[2,4] (13.1) | 86[3] (8.7) | | | | |
| SEPTA | | 87[5] (16.7) | | 77[5,6] (2.1) | | | | | |
| PATCO[7] | | | 94 (1.7) | | | 76 (2.0) | | 81 (3.0) | 83 (16.7) |
| RTA[8] | | | | | 99 (17.1) | 93 (17.7) | | | 84 (1.3) |
| BART[9] | | | 91 (46.0) | | 86 (55.3) | | | | |
| CTA[10] | 85 (35.7) | 97 (71.3) | 92 (2.4) | 86 (10.8) | 86 (5.6) | 89 (5.1) | 84 (13.6) | | 75 (9.8) |
| NYCTA & SIRT[11] | | 92 (121.8) | 84 (11.4) | 82 (16.0) | | 76 (30.2) | 84 (8.0) | | |

NOTES:

1 - MBTA Orange Line Cars (1959)
2 - MBTA Red Line Bluebirds (1962)
3 - MBTA Red Line Silverbirds (1968)
4 - MBTA Blue Line Cars (1935-1954)
5 - SEPTA Market - Frankford Line Cars (1960)
6 - SEPTA Broad Street Subway Cars (1928)
7 - PATCO - Budd Company Cars (1969)
8 - RTA St. Louis Single or Double Cars (1955, 1958), or Pullman Single Cars (1967)
9 - BART A and B Cars (1972+)
10 - CTA 2000, 2200, or 6000 Cars (1964, 1969 - 1970, and 1950's), Adjusted for Train Speeds
11 - NYCTA R-44 (1972), IRT Cars (1948-1963), or Non-R-44/Non-IRT Cars (1948-1970)

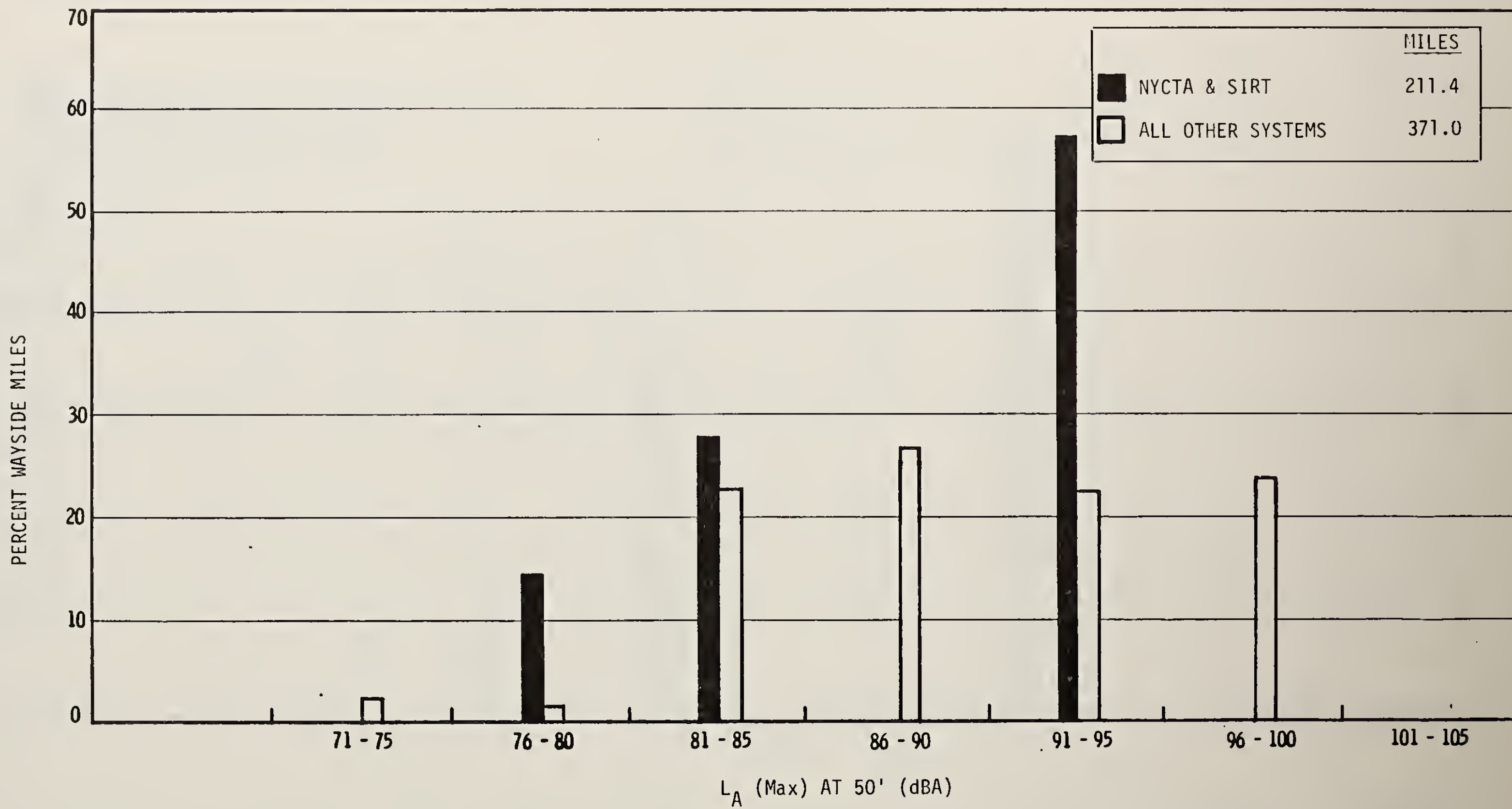


FIGURE 4-12 COMPOSITE SYSTEM, DISTRIBUTION OF WAYSIDE AVERAGE MAXIMUM PASS-BY NOISE LEVELS

general patterns. The highest $L_A$(Max) levels are adjacent to elevated steel track, the lowest levels, open-cut track.

The points discussed above become apparent as the individual systems are compared. More than 98 percent of the steel elevated mileage of CTA and MBTA exhibits pass-by levels ranging between 92 and 101 dBA, with the higher levels occurring at CTA sections where the trains operate at a speed of approximately 40 mph. Conversely, all elevated steel track on SEPTA properties has a $L_A$(Max) level of less than 89 dBA, even on track where the average operating speed is 45 mph. This variation in $L_A$(Max) levels shows the effect of differences in roadbed construction between SEPTA, where the steel elevated structure supports a concrete sub-base on which ballast and ties are laid, and the other systems, where the rail is mounted directly onto open-decked steel structure. However, it should be noted that similar types of track structure and roadbed construction exhibit a wide range in $L_A$(Max) levels. Differences in $L_A$(Max) levels may be explained in part by differences in train speeds. Along elevated sections of SEPTA, for example, a reduction in speeds from 45 to 20 miles per hour was accompanied by a two or three dBA decrease in $L_A$(Max) levels.

More than 96 percent of the aboveground right-of-way on RTA is comprised of open-cut or at-grade track. Adjacent to this track, wayside $L_A$(Max) levels of 93 (open-cut) and 99 (at-grade) dBA, are observed. These levels are between 13 and 17 dBA higher than the average levels recorded on similar track on other systems. The mismatch between wheel and track gauge, as discussed in Appendix D, is suspected to be one of the factors causing this increase.

#### 4.4.2 $L_{dn}$(Trains)

The wayside day-night equivalent sound levels considering only train pass-by noise, represented by $L_{dn}$(Trains), are based on the wayside $L_A$(Max) pattern, as well as on the number and duration of train pass-bys.

Table 4-5 aggregates the wayside mileage by $L_{dn}$(Trains) level for all routes excpet those in New York City. The same general patterns discussed in the $L_A$(Max) description are also apparent

TABLE 4-5 COMPOSITE SYSTEM, WAYSIDE $L_{dn}$ (TRAINS)

| SYSTEM | $L_{dn}$(TRAINS) RANGE | WAYSIDE MILES |
|---|---|---|
| CTA | 62 - 87 dBA | 153.2 |
| BART | 63 - 73 dBA | 101.3 |
| MBTA | 66 - 77 dBA | 38.2 |
| RTA | 63 - 79 dBA | 36.1 |
| PATCO | 56 - 74 dBA | 23.4 |
| SEPTA | 63 - 74 dBA | 18.8 |
| **$L_{dn}$(TRAINS) LEVEL** | **WAYSIDE MILES** | **PERCENT WAYSIDE MILES** |
| 56 | 2.0 | .5 |
| 62 | 9.8 | 2.6 |
| 63 | 25.8 | 7.0 |
| 64 | 3.0 | .8 |
| 65 | 5.9 | 1.6 |
| 66 | 26.5 | 7.1 |
| 67 | 31.9 | 8.6 |
| 68 | 28.7 | 7.7 |
| 69 | 23.8 | 6.4 |
| 70 | 14.6 | 3.9 |
| 71 | 6.1 | 1.6 |
| 72 | 52.8 | 14.2 |
| 73 | 14.8 | 4.0 |
| 74 | 19.7 | 5.4 |
| 75 | .4 | .1 |
| 76 | .3 | .1 |
| 77 | 15.2 | 4.1 |
| 78 | 7.2 | 1.9 |
| 79 | 13.6 | 3.7 |
| 80 | 5.1 | 1.4 |
| 81 | 16.0 | 4.3 |
| 82 | 9.3 | 2.5 |
| 83 | 2.0 | .5 |
| 84 | 3.8 | 1.0 |
| 85 | 26.6 | 7.2 |
| 86 | 3.5 | .9 |
| 87 | 2.6 | .7 |

TOTAL WAYSIDE MILES = 371.0

in this case. The highest $L_{dn}$(Trains) levels are recorded alongside elevated steel track. The levels experienced adjacent to RTA track are generally significantly higher than those recorded alongside similar types of track on other routes. The elevated sections of SEPTA exhibit $L_{dn}$(Trains) levels 5 dBA lower than the lowest level experienced by wayside areas adjacent to CTA elevated steel rights-of-way.

One determinant responsible for observed variations in $L_{dn}$(Trains) levels is the number of train pass-bys, particularly night pass-bys. Within the CTA system, $L_{dn}$(Trains) levels recorded in communities adjacent to elevated steel track vary from 81 to 86 dBA, even though identical $L_A$(Max) levels are observed in these communities. This was also true for other wayside areas on other systems, notably RTA and BART.

The duration of train pass-bys, which is determined by train speed and length, is also a factor in varying the $L_{dn}$(Trains) level. Generally, an increase in speed decreases the $L_{dn}$(Trains) level. However, the effect of speed is minimized since a speed increase will generate an increase in the wayside $L_A$(Max) level. For a more detailed description of this phenomena, see Appendix J. The effect of speed on the SEPTA system is discussed in Appendix B.

On the two representative NYCTA routes, the $L_{dn}$(Trains) levels range from 61 to 91 dBA, with the wayside $L_A$(Max) levels ranging from 76 to 102 dBA. The patterns discussed earlier are also present in this case. On each route, the highest $L_{dn}$(Trains) levels exist in communities abutting elevated steel trackage. Differences in the number of train pass-bys between elevated steel segments with identical wayside $L_A$(Max) levels on one of the routes, the IND-D, are responsible for observed variations in the $L_{dn}$(Trains) levels from 88 to 91 dBA.

#### 4.4.3 $L_{dn}$(Ambient)

The $L_{dn}$(Ambient) characterizes community noise generated by all sources other than train pass-bys. The levels listed below are averages of $L_{dn}$(Ambient) values; they range from 49 to 73 dBA

for the six systems in the Composite System, and from 61 to 75 dBA for NYCTA's two representative routes.

a. MBTA --- 64 dBA
b. SEPTA -- 67 dBA
c. PATCO -- 59 dBA
d. RTA ---- 63 dBA
e. BART --- 60 dBA
f. CTA ---- 66 dBA
g. Above six systems combined - 63 dBA.
h. NYCTA's two representative routes - 69 dBA.

The $L_{dn}$(Ambient) values were determined from residential population densities as discussed in Appendix J.

4.4.4 <u>Relative $L_{dn}$</u>

The Relative $L_{dn}$ is the amount by which the $L_{dn}$ from all noise sources (including trains) differs from the $L_{dn}$(Ambient). It reflects both the $L_{dn}$(Trains) pattern shown in Table 4-4 and the $L_{dn}$(Ambient) distribution discussed above.

Figure 4-13 illustrates the percent residential miles by Relative $L_{dn}$ level for the Composite System and for the two representative routes of the NYCTA. The levels range from one to 36 dBA for the aggregated systems and from 2 to 19 dBA for NYCTA's two routes. Less than 2 percent of the total residential mileage of the aggregated systems has Relative $L_{dn}$ levels greater than 20 dBA.

The wayside adjacent to the CTA system right-of-way shows the greatest range in Relative $L_{dn}$ levels, from 1 to 36 dBA, with a mileage-weighted mean of 11 dBA. The ranges and means for the remaining five systems are as follows:

a. MBTA - 1 to 16 dBA; 9 dBA
b. SEPTA - 2 to 25 dBA; 8 dBA
c. PATCO - 1 to 14 dBA; 6 dBA
d. RTA - 2 to 18 dBA; 12 dBA
e. BART - 2 to 19 dBA; 11 dBA

Relative $L_{dn}$ levels range from 2 to 16 dBA, with a mean of 5 dBA

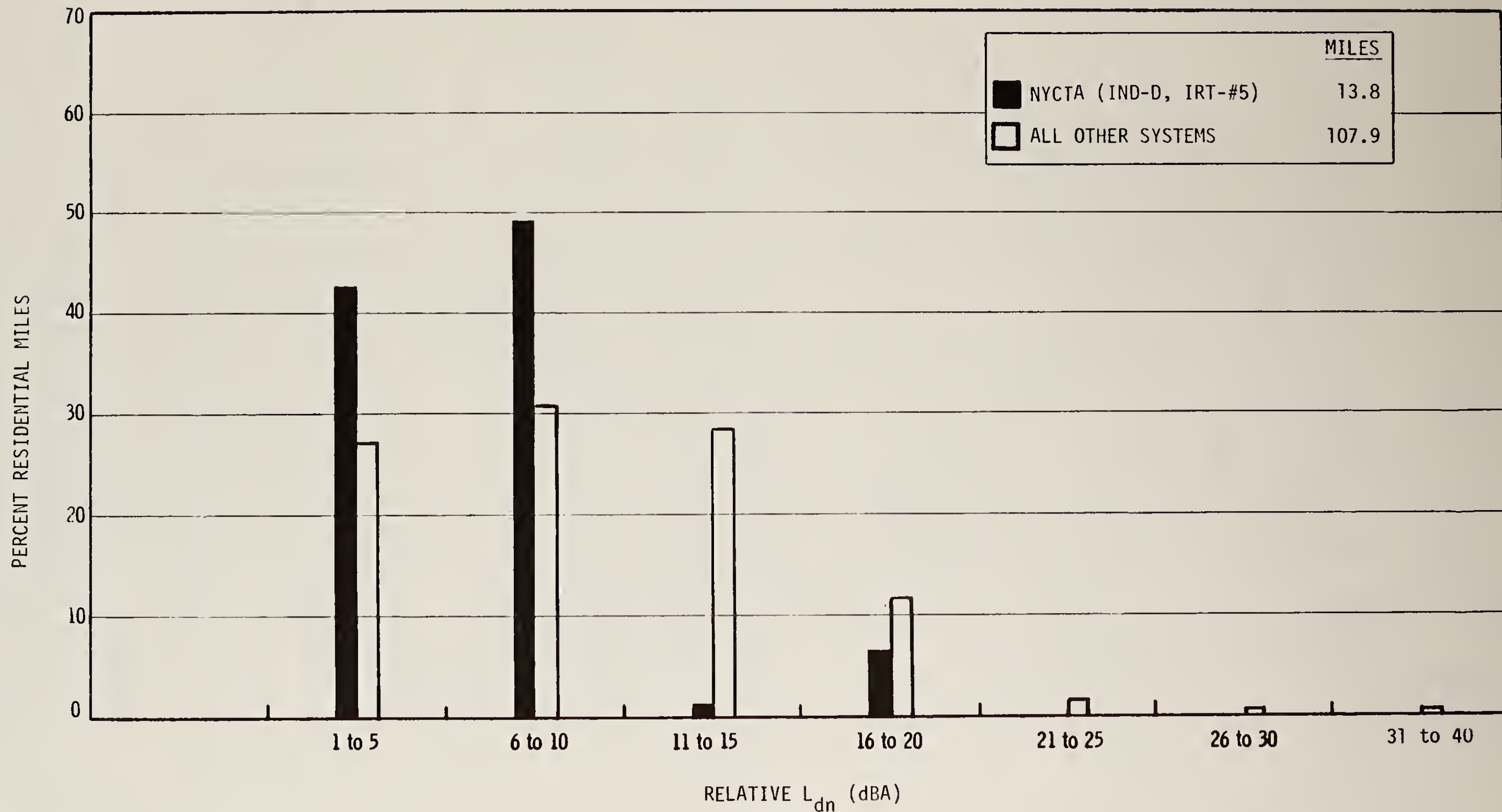


FIGURE 4-13 COMPOSITE SYSTEM, DISTRIBUTION OF WAYSIDE RELATIVE $L_{dn}$

for the IRT-#5, and from 2 to 19 dBA, with a mean of 8 dBA adjacent to the IND-D right-of-way.

Examining the Composite System, one finds low Relative $L_{dn}$ levels of 1 to 5 dBA in approxmiately 27 percent of the residential areas. In these communities, $L_{dn}$(Ambient) levels contribute significantly to the Relative $L_{dn}$ as, in many cases, the ambient levels are greater than, or equal to, the $L_{dn}$(Trains) level.

Conversely, only 13 percent of the residential areas adjacent to the Composite System experience Relative $L_{dn}$ levels resulting solely from train pass-by noise. Relative $L_{dn}$ levels of 16 to 20 dBA are found in communities where either low ambient levels (49 to 60 dBA) are combined with high trains levels (71 to 80 dBA) or medium ambient levels (61 to 70 dBA) with high and very high (81 to 86 dBA) trains levels. The high (21 to 25 dBA) and very high (>25 dBA) Relative $L_{dn}$ levels are found almost exclusively on the CTA system adjacent to steel elevated track. The high Relative $L_{dn}$ levels are observed primarily in communities where medium $L_{dn}$ (Ambient) levels are combined with very high $L_{dn}$(Trains) levels, and the very high Relative $L_{dn}$ values are in areas where low ambient levels are combined with very high trains levels.

NYCTA's two representative routes follow a different pattern. Approximately 42 percent of the residential mileage experiences low Relative $L_{dn}$ levels (1 to 5 dBA). They occur in communities where medium $L_{dn}$(Ambient) levels are combined with medium $L_{dn}$(Trains) levels, or high ambient levels (71 to 80 dBA) combine with high trains levels. At the other extreme, the highest Relative $L_{dn}$ levels observed on the two routes (16 to 19 dBA) affect 6 percent of the residential communities and are found where medium ambient levels are combined with very high train levels (81 to 89 dBA). No low $L_{dn}$(Ambient) levels (49 to 60 dBA) are found in any residential community abutting either the IRT-#5 or the IND-D route.

4.4.5 Wayside Exposure

The total population within the 200-foot corridor along above-ground segments of the Composite Rail System is estimated to be approximately 63,100. More than half of this total, 58 percent,

resides in communities adjacent to the CTA right-of-way. The remaining population is distributed as follows: BART - 16 percent, MBTA and SEPTA - 9 percent, RTA - 5 percent and PATCO - 3 percent.

For the two NYCTA routes, representing only 14 percent of the total aboveground mileage in New York City, the population within the wayside corridor is estimated at 22,400.

Figure 4-14 illustrates the percent residential population by the Relative $L_{dn}$ ranges. Only approximately 15 percent of the population adjacent to the right-of-way of the Composite System, and 8 percent residing alongside the two representative routes in New York are exposed to Relative $L_{dn}$ levels greater than 15 dBA.

### 4.4.6 Comparison of Wayside $L_A$(Max) with APTA Guidelines

Figure 4-15 shows distributions of wayside $L_A$(Max) at 15m (50 ft), relative to the APTA goals for new systems, at the building line of residential and non-residential uses abutting the rail right-of-way.

Approximately 3 percent of the aggregated systems in the Composite and 4 percent of the NYCTA and SIRT total wayside mileage are within the established goals. The majority of the wayside, 56 percent for the Composite System and 58 percent for the two New York City authorities, is exposed to $L_A$(Max) levels more than 10 dBA higher than the APTA goals.

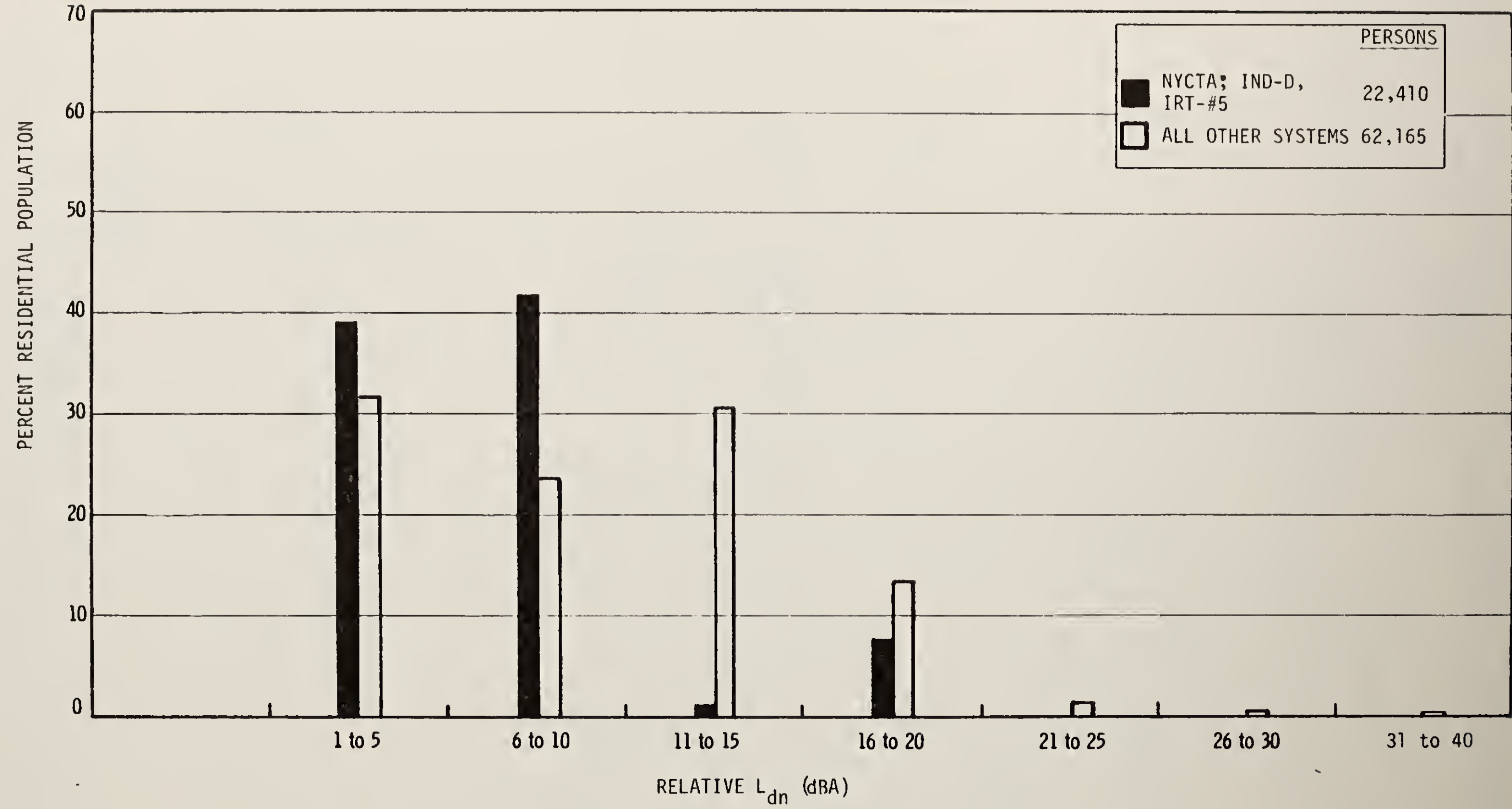


FIGURE 4-14 COMPOSITE SYSTEM, WAYSIDE NOISE EXPOSURE

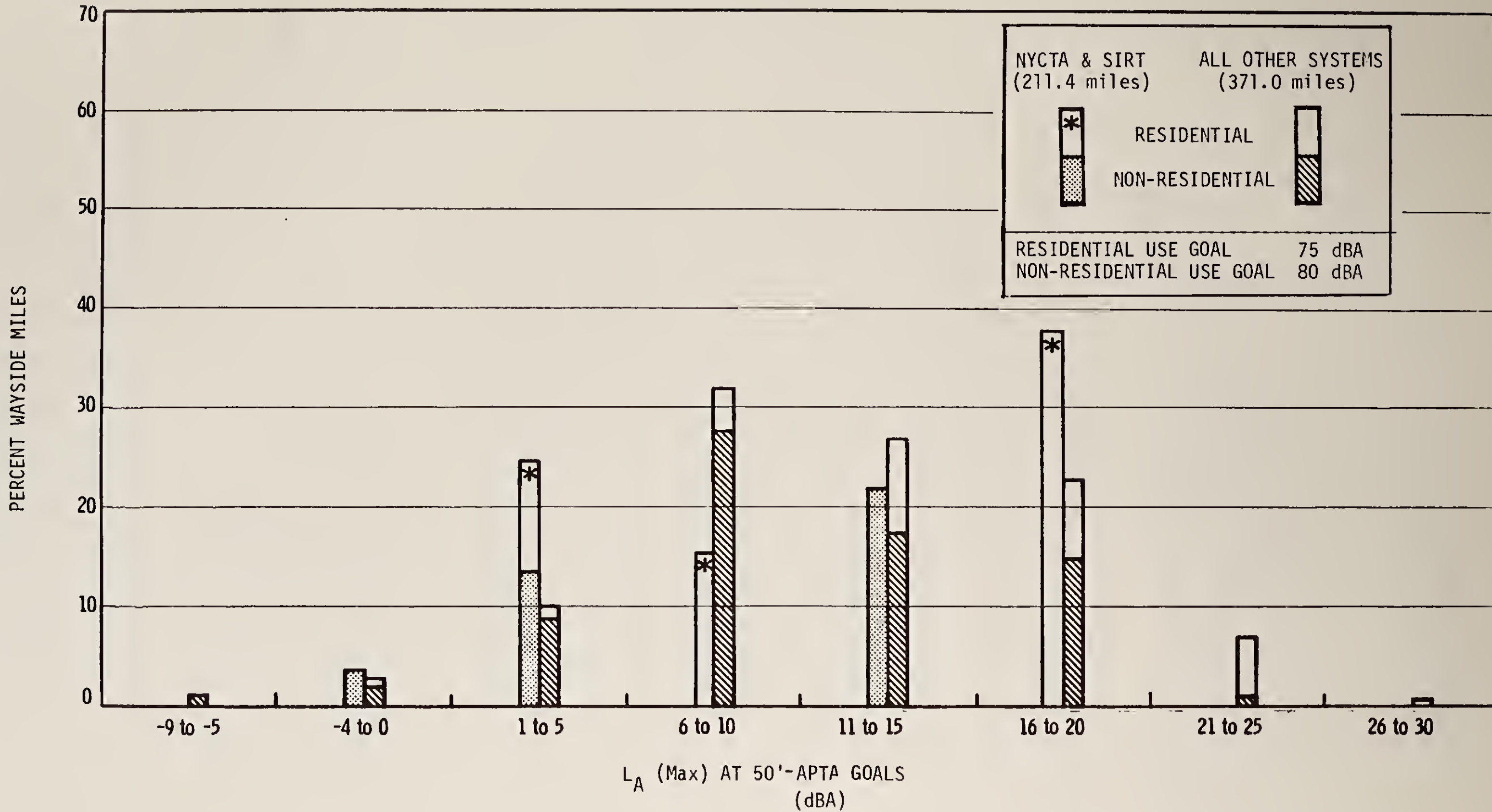


FIGURE 4-15 COMPOSITE SYSTEM, WAYSIDE NOISE GOAL COMPARISON

# 5. SUMMARY AND RECOMMENDATIONS

## 5.1 NOISE ASSESSMENT SUMMARY

A summary of noise levels and exposure to rail noise in each of the seven rail transit systems studied is given in Table 5-1. Section 4, the Composite Rail System, summarizes the national distributions of noise levels and noise exposure for each of the receiver environments.

This assessment should be useful for the following purposes: determining the severity and distribution of the U.S. transit noise problem; comparing noise levels of urban rail transit with those of other modes; evaluating the potential impact of proposed regulations for rail noise; and estimating noise abatement requirements.

The methodology used in this assessment involved making several generalizations about noise sources, noise attenuation, patterns of ridership, and wayside residential densities. The information presented must be supplemented to provide reliable support for site-specific tasks such as the application of noise abatement techniques, land use planning for development near the rail rights of way, and determination of the attitudinal and physiological impacts of exposure to rail noise.

## 5.1 RECOMMENDATIONS FOR ASSESSMENT METHODOLOGIES

Sound Level Assessment

1) Several acoustical measures are appropriate to some degree for assessing rail transit noise, although none appears ideal. The maximum sound levels, $L_A$(Max), are most suited for use as equipment design standards, and give an indication of the most severe noise a receiver experiences. The equivalent sound level, $L_{eq}$, and day-night equivalent sound level, $L_{dn}$, account for the duration of a sound event as well as the intensity, and also reflect the number of sound events in a given period of time. However, $L_{eq}$ and $L_{dn}$ do not indicate the strength, and thus the degree of potential annoyance, of each individual sound event. The impact of

## TABLE 5-1 SUMMARY - NATIONAL URBAN RAIL NOISE ASSESSMENT

| | MBTA (Boston) | SEPTA (Philadelphia) | PATCO (New Jersey) | RTA (Cleveland) | BART (San Francisco) | CTA (Chicago) | NYCTA-2LINES (New York) |
|---|---|---|---|---|---|---|---|
| Route Length (ROW Miles) | 34.9 | 23.7 | 14.2 | 19.0 | 70.4 | 86.3 | 45.6 |
| Average Daily Ridership | 234,000 | 337,100 | 39,500 | 37,100 | 118,800 | 527,350 | 364,500 |
| Wayside Population Within 200 Feet | 5,750 | 5,500 | 2,000 | 2,800 | 9,800 | 36,250 | 22,400 |
| **IN-CAR NOISE** | | | | | | | |
| Average Inter-Station $L_A$(Max)-dBA | 82 | 85 | 76 | 83 | 80 | 85 | 90 |
| (Standard Deviation)-dBA | (6.1) | (5.9) | (3.2) | (1.5) | (3.3) | (3.7) | (4.2) |
| $L_{eq}$(R)-dBA* | 79 | 84 | 73 | 81 | 78 | 84 | 89 |
| **IN-STATION NOISE** | | | | | | | |
| Average Station $L_A$(Max)-dBA | 87 | 92 | .8C | 82 | 80 | 85 | 100 |
| (Range)-dBA | (80-93) | (80-98) | (70-89) | (77-88) | (76-85) | (75-103) | (83-112) |
| Average Station $L_{eq}$-dBA | 76 | 80 | 72 | 73 | 69 | 75 | 87 |
| **WAYSIDE NOISE** | | | | | | | |
| Average $L_A$(Max) in Residential Areas at 50 Feet-dBA | 87 | 86 | 84 | 95 | 89 | 92 | 87 |
| (Range)-dBA | (83-92) | (76-89) | (76-94) | (84-99) | (86-91) | (74-101) | (76-102) |
| Average Relative $L_{dn}$-dBA | 9 | 8 | 6 | 12 | 9 | 11 | 7 |

*Average in-car $L_{eq}$ level for entire system.

single events may be particularly important in relatively quiet areas. It seems appropriate, therefore, to consider both maximum and average sound levels in making an assessment of noise exposure. It should also be noted that none of the above noise descriptors take into consideration the tonal content of the sound. The choice of the noise measures used will ultimately depend on development of improved criteria for assessing noise exposure -- speech interference, annoyance, and hearing loss all could be related to transit noise levels.

2) The National Assessment has often made generalizations about sound level measures based on a few representative samples, particularly in the case of the wayside community and transit stations. A larger number of measurements is needed to document noise singularities, or "hot spots." They include wheel squeal and noise from door operation, unmuffled air brakes, and track geometry irregularities. The tonal content and the irregularity of occurrence make these noises particularly annoying.

3) Noise level assessment methodology for each reciever environment should consider also:

a. <u>In-Car Noise</u>

- Effect of passenger density on noise level.
- Vehicle speed.
- Use of car-miles rather than route-miles as a basis for the in-car assessment. The car-miles measure would weight the route mileage by the number of operations, and thus be directly related to the amount of in-car exposure. The route-miles measure is oriented towards estimating the extent of noise abatement treatment needed on a system.

b. <u>Station Noise</u>

- Patron density on station platform,
- The rate of increase in noise level as a train enters a station in order to estimate the startle effect of the noise.

- Sources of noise other than trains, such as public address system; or in the case of aboveground stations, adjacent modes of transportation.
- Measurement of station reverberation times, so that the relative contribution of reverberant and direct radiation can be determined.
- Station dimensions and methods of construction, with particular attention to placement of barriers, width of platforms, and types of acoustical treatment.
- Noise levels in fare collection booths.
- Variation in noise levels at different points within the station with respect to both intensity and duration.

c. Wayside Noise

- Dimensions of track structure (e.g., cutting and embankment widths, and height of elevated structures). These can have significant effects on sound propagation.
- Types of ground surfaces, reflective building walls, and vegetation, which may affect sound propagation and attenuation.
- Relation of wayside pass-by levels to in-car sound levels, or to near field car exterior noise levels (measured while moving within the car). These types of measurements would avoid the problem of field measurement sites, and would provide a more comprehensive wayside noise assessment. Variations in wayside levels relative to train speed and acceleration, and noise-producing singularities, could be documented.
- Ground vibration from pass-bys, particularly in the community adjacent to underground track.

- Adjacent modes of transportation which contribute considerably to noise levels in the community.
- For site specific studies, on-site measurement of wayside ambient noise levels. The estimates made in the National Assessment are based on population density and the associated traffic noise expected. Ambient levels will actually vary in relation to distance from streets, location of buildings, and other sources of noise in the community.

4) Noise levels in all three environments are affected by the conditions of wheels, rails, and other equipment, which should be documented.

5) For noise abatement design diagnostic measurement techniques should be employed in all three receiver environments to identify the relative contributions of various noise sources and paths.

Exposure Assessment

The assessment of the number of persons exposed to train noise in each of the receiver environments should include:

1) Determination of the actual number of riders travelling on specific route segments. Given this type of data, one can determine the number of riders exposed to each in-car noise level, without making the assumptions about average trip time and distribution of noise levels on a trip used in the National Assessment methodology.

2) Location on the station platform of benches or other indicators of passenger locations (to relate patron locations with possible variations in noise level and noise duration within a station).

3) Direct enumeration of wayside population rather than derivation of the population from gross densities. If this is not possible, it would be more accurate to use net residential densities rather than gross densities, assuming the determination of the

location of residential areas is accurate.

4.a) Determination of distance from the track to the nearest building or impacted area in the wayside community;

b) Determination of the wayside population within contours for a given noise level.

5) Relationships between outdoor noise levels and noise levels inside buildings for receivers in the wayside. The impact of pass-by noise can be expected to vary with building construction and the presence of other sources of interior noise.

6) The total impact of various noise levels considering the receiver's entire pattern of noise exposure throughout a day.

7) Impact assessed in terms of factors such as age and sex.

8) Possible use of other measures to assess noise exposure. For example, fractional impact methods compare the noise levels with a given noise level (commonly chosen with respect to criteria for speech interference).

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# APPENDIX A - URBAN RAIL NOISE ASSESSMENT OF MBTA SYSTEM

## A.1 SYSTEM DESCRIPTION (See Table A-1)

The Massachusetts Bay Transit Authority (MBTA) operates three rapid transit lines in metropolitan Boston. The three lines are color-coded as the Red Line, Blue Line and Orange Line (Figure A-1). A short description of the system at the time of the noise measurements follows.

The system criss-crosses the Boston area in a roughly east-west and north-south pattern. The nearly 48 km (30 mi) (R.O.W.) of track are built on three types of structures - at-grade (42 percent), elevated steel (29 percent) and subway (29 percent). Except for the at-grade segment on the South Shore Extension of the Red Line, all rail is jointed (occasionally field-welded) and set on wood ties in ballast. The South Shore Extension has continuously welded rail set on concrete ties in ballast.

Since the compilation of the noise measurements, parts of the Orange Line have been reconstructed and an additional 8.4 km (5.2 mi) added to the overall route mileage. The at-grade sections of the line, as they presently exist, are welded rail on wood ties in ballast.

### A.1.1 Stations

Of the 44 stations on the combined MBTA operations, the most prevalent type of platform configuration is the side platform (60 percent). The second most frequent configuration is the center platform (27 percent).

Except for one station on each route, Fields Corner on the Red Line, Aquarium on the Blue Line, and Essex on the Orange Line, no acoustical treatments have been introduced. On these stations the acoustical treatments consist of ceiling and wall panels backed by a layer of fiberglass insulation.

TABLE A-1 MBTA SYSTEM SUMMARY (1 of 2)

| | ORANGE LINE* | RED LINE | BLUE LINE | MBTA Total* |
|---|---|---|---|---|
| A. ROUTE PHYSICAL DESCRIPTION | | Ashmont/S. Shore Ext. | | |
| 1. Length | 14 Miles | 8.8 Miles/11.4 Miles | 6 Miles | 34.9 Miles |
| 2. Track Type | Jointed, Wood Ties, Ballast<br>Welded, Wood Ties, Ballast. | Jointed, Wood Ties, Ballast/<br>Welded, Concrete Ties, Ballast. | Jointed, Wood Ties, Ballast. | |
| 3. Track Structure Mileage | | | | |
| a. Subway | 3 Miles | 5.7/4.8 Miles | 2 Miles | 10.8 Miles |
| b. Steel Elevated | 4 Miles | .6/.6 Miles | | 4.6 Miles |
| c. At-Grade | 7 Miles | 2.5/6.0 Miles | 4 Miles | 19.5 Miles |
| 4. Number of Stations | 15 | 17 | 12 | 44 |
| B. VEHICLES | | | | |
| 1. Years Manufactured | 1959 | 1963/1970 | 1939, 1954 | |
| 2. Number in Service | 100 | 92/76 | 24, 51 | |
| 3. Acoustical Treatment | No | No/Yes | No | |
| C. SYSTEM SCHEDULING | | | | |
| 1. Running Time | 40 Minutes | 25 Minutes/25 Minutes | 18 Minutes | |
| 2. Average Running Speed | 23 mph | 30 mph/36 mph | 30 mph | |
| D. POPULATION DATA | | | | |
| 1. Daily Ridership | 70,860/day | 130,000/day | 33,585/day | 234,000/day |
| 2. Mean Wayside Pop. Density | 22,150/sq.mi. | 23,290/sq.mi. | 11,760/sq.mi. | 21,480/sq.mi. |
| 3. Wayside Pop. Witihin 200 ft. | 2,030 persons | 3,330 persons | 390 persons | 5,750 persons |
| 4. Residential Land Use (Length - % Total Wayside) | 3.2 Miles (21.1%) | 5.0 Miles (33.3%) | 1.2 Miles (15.0%) | 9.4 Miles (24.8%) |

*Route description (Item A) is for transit system as of March, 1977. See Section A.1.3 for explanation of changes since noise measurements were taken. (MBTA Total is R.O.W. Mileage.)

## TABLE A-1 MBTA SYSTEM SUMMARY (2 of 2)

| | ORANGE LINE | RED LINE Bluebirds/Silverbirds | BLUE LINE | MBTA TOTAL |
|---|---|---|---|---|
| E. IN-CAR NOISE | | | | |
| 1. Average Interstation $L_A(Max)$ | 81.7 dBA | 84.4 dBA / 74.2 dBA | 87.7 dBA | 82.0 dBA |
| 2. $L_A(Max)$ - Standard Deviation | 3.4 dBA | 3.2 dBA / 4.2 dBA | 2.5 dBA | 6.1 dBA |
| 3. $L_{eq}(R)$ | 79.5 dBA | 82.2 dBA / 72.0 dBA | 85.5 dBA | 79.0 dBA |
| F. IN-STATION NOISE | | | | |
| 1. Average Station $L_A(Max)$ | 82.6 dBA | 88 dBA | 89 dBA | 86.9 dBA |
| 1.5 Range of $L_A(Max)$ | 80-87 dBA | 83-93 dBA | 85-92 dBA | 80-93 dBA |
| 2. Average Station $L_{eq}$ | 78 dBA | 77 dBA | 71.6 dBA | 75.6 dBA |
| G. WAYSIDE COMMUNITY NOISE | | | | |
| 1. Average $L_A(Max)$ @ 50 ft. | 92 dBA | 85.1 dBA | 86 dBA | 87.3 dBA |
| 1.5 Range of $L_A(Max)$ @ 50 ft. | 92 dBA | 83-89 dBA | 86 dBA | 83-92 dBA |
| 2. Average $L_{dn}$(Trains) | 77 dBA | 68.7 dBA | 70 dBA | 72.3 dBA |
| 3. Average $L_{dn}$(Ambient) | 64.6 dBA | 63.8 dBA | 61.6 dBA | 63.8 dBA |
| 4. Average Relative $L_{DN}$ | 12.8 dBA | 6.0 dBA | 9.2 dBA | 8.7 dBA |

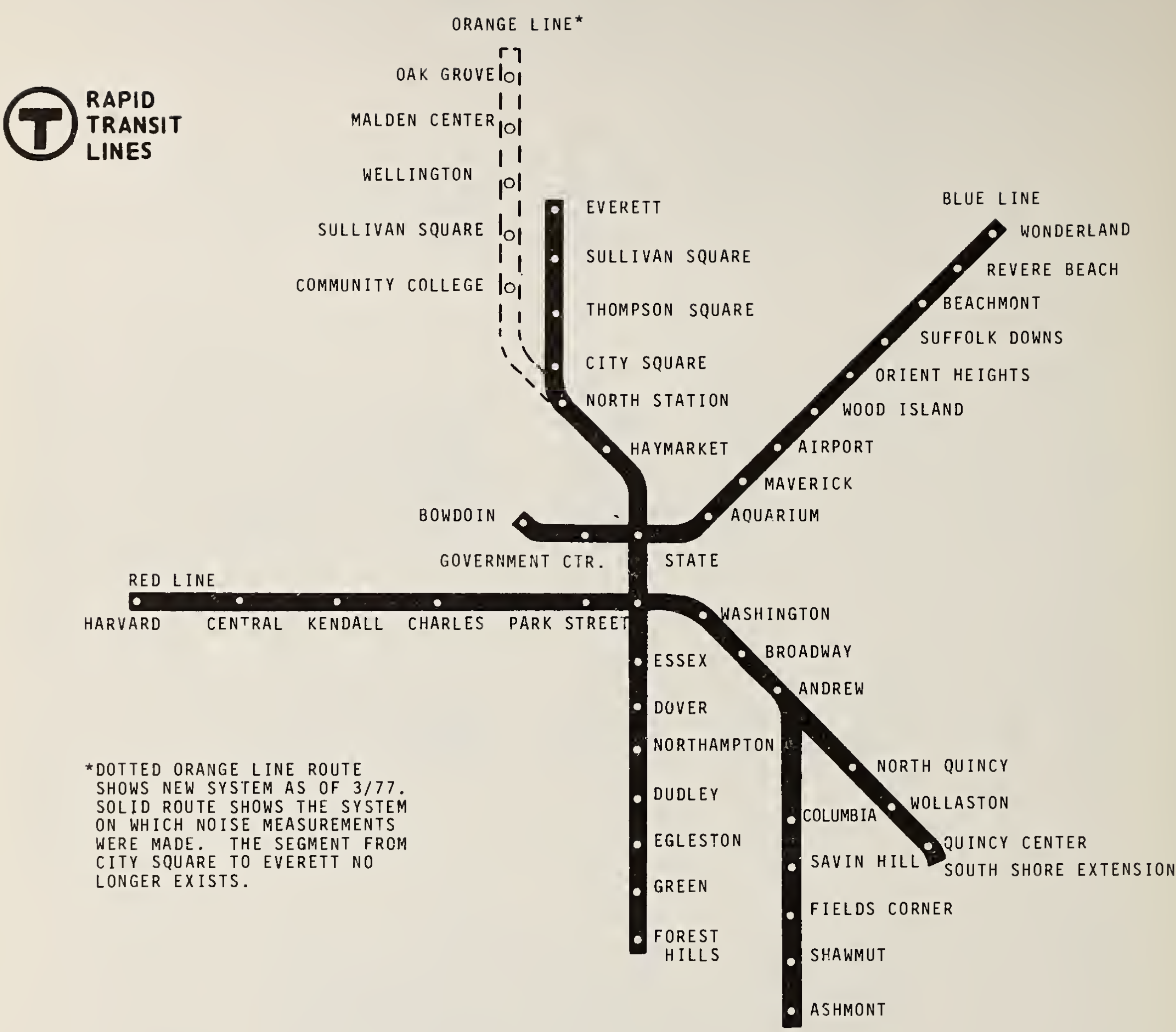



FIGURE A-1 MBTA RAPID TRANSIT LINES - SCHEMATIC

With the reconstruction of the Orange Line, four stations were eliminated and five new stations added, for a present total of 45 stations.

### A.1.2 Transit Vehicles

The transit fleet is comprised of 343 rail vehicles, of which 75 operate on the Blue Line, 100 on the Orange Line, and 168 on the Red Line.

One-third of the Blue Line vehicles are 37 years old and scheduled for replacement within the next few years. They are 14.5 m (47-1/2 ft) long and have a seating capacity of 44 passengers. The remainder of the Blue Line cars are 20 years old, 14.8 m (48-3/4 ft) long and seat 46 passengers. Neither car model is air-conditioned or acoustically treated.

The Orange Line cars on the average are 15 years old, measure 55 feet in length and have a seating capacity of 46 passengers. These cars are not acoustically treated.

Ninety-two of the Red Line vehicles were built in 1963 and are called "Bluebirds" because of their blue exteriors. They seat 54 and measure 21.2 m (69-1/2 ft) in length. They are not air-conditioned or acoustically treated. The remaining Red Line vehicles, called "Silverbirds" because of their brushed aluminum exterior finish, were acquired in 1970. They are 21.2 m (69-1/2 ft) in length, have a seating capacity of 64 passengers, and are air-conditioned. They have a high car-body acoustic transmission loss.

### A.1.3 Route Descriptions

The 8.6 km (six mi) of double track known as the Blue Line runs from central Boston (Bowdoin Station) east toward Logan Airport and the beaches along the shore. The initial 3.2 km (two mi), from Bowdoin to just beyond Maverick, are underground. The remaining 6.4 km (four mi) to the terminal at Wonderland are at-grade.

At an average speed of 48 km/h (30 mph), the running time along the line is 18 minutes. Headways range from 15 minutes to

three minutes, depending on the time of day.

At the time the noise measurements were taken, the Orange Line was 14.2 km (8.8 mi) long. The system began at Everett Station in North Boston and ran south on a steel elevated structure for 4.5 km (2.8 mi) to North Station (which was elevated at the time). There it entered a 2.2 km (1.4 mi) tunnel for four underground stations, the last being Essex. The remainder of the system, then as today, was elevated steel.

Running time from end-to-end was approximately 30 minutes, with an average speed of 37 km/h (23 mph). Headways varied from 15 minutes at night to four minutes during the pead periods.

The Orange Line is presently 22.4 km (14 mi) long. Starting from Oak Grove Station, north of Boston, the line runs on at-grade track for 11.2 km (seven mi) to Community College Station. There it enters a 4.8-km (three-mile) tunnel for five underground stations, the last being Essex Station. The line emerges from the subway and continues once again on steel elevated structure to the terminal at Forest Hills.

Headways range from 15 minutes to four minutes during the day. The running time is 40 minutes, with an average operating speed of 37 km/h (23 mph).

The Red Line starts at Harvard Square Station and goes to Andrew Station, where it branches, one branch going to Ashmont Station and the other to Quincy Center. The initial 3.5 km (2.2 mi) from Harvard Square are underground as far as Kendall Station. The line then crosses the Charles River on the Longfellow Bridge and is on elevated track for 1 km (0.6 mi). The next 4.2 km (2.6 mi) to Andrew Station are underground. Beyond Andrew the line is at-grade, 4.2 km (2.6 mi) and underground, 1.4 km (0.9 mi) to Ashmont) during normal operations. The Quincy Center branch, known as the South Shore Extension, covers six miles of grade level track, starting at Andrew and ending at Quincy Center. Only Silverbirds operate on this branch. Both types of cars operate between Andrew and Harvard Square Stations.

The running time for each of the branches is 25 minutes. The average travelling speeds are 48 km/h (30 mph) for the Ashmont to Harvard run and 58 km/h (36 mph) for the Quincy to Harvard run. Headways range from four to 15 minutes, with the lower headways occurring on the South Shore Extension.

The MBTA operates all of its lines from approximately 5:15 A.M. until 12:40 A.M. Only two- or four-car trains are employed.

## A.2 IN-CAR NOISE

### A.2.1 $L_A$(Max)

As can be seen in Figures A-2, A-3, and A-4, the lowest in-car noise plateau levels (70 dBA) are found on the Silverbirds along the at-grade, continuously welded rail sections of the South Shore Extension. The $L_A$(Max) increases only slightly over this base in-car level along the remainder of the route, giving the South Shore Extension the lowest range of values (70 to 81 dBA) on the entire system. The Orange Line transit cars and the Bluebirds of the Red Line have similar noise level ranges (75 to 95 dBA). The distribution of route miles vs $L_A$(Max) on the Orange Line, however, is skewed slightly toward the lower end, while the Bluebird distribution is skewed toward the upper end of the $L_A$(Max) range, reflecting the greater mileage of underground track on the Red Line. The highest in-car $L_A$(Max) levels on the MBTA are found along the Blue Line. The levels range from a low of 85 dBA to a high of 93 dBA.

Table A-2, the In-Car Summary, gives a clearer comparison of maximum noise levels. The table shows that for the various types of track structure the difference in the average $L_A$(Max) between the transit cars on the Blue Line and the cars on the other lines is consistent with the disparity in age between the two groups, the Blue Line cars being older. The distribution of route miles with $L_A$(Max) for the entire MBTA system is shown in Figure A-5.

### A.2.2 In-Car Equivalent Noise Level

The MBTA system has been characterized by four route equivalent noise levels, $L_{eq}$(R), each corresponding to one of the lines

# LEGEND FOR FIGURES A-2 TO A-4

TRACK STRUCTURE

- ES = ELEVATED STEEL
- EE = ELEVATED EMBANKMENT
- UG = UNDERGROUND
- CV = CONCRETE VIADUCT
- IC = IN CUT
- AG = AT GRADE
- MS = MEDIAN STRIP
- EC = ELEVATED CONCRETE
- A = AERIAL

$X_{AB}$ = INTERSTATION DISTANCE (MILES)

$N_A/N_B$ = STATION NOISE AT STATION A/B (dBA)

$N_i$ = IN-CAR NOISE (dBA)

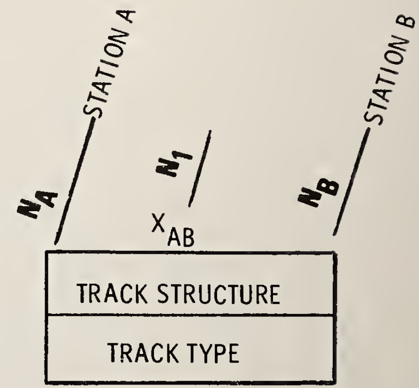
$N_{50}$ = WAYSIDE NOISE AT 50 FEET (dBA)

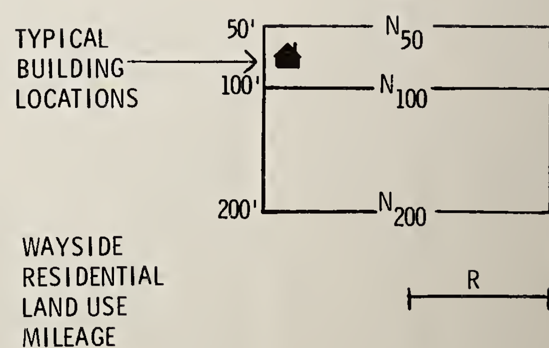
$N_{100}$ = WAYSIDE NOISE AT 100 FEET (dBA)

$N_{200}$ = WAYSIDE NOISE AT 200 FEET (dBA)

R = WAYSIDE RESIDENTIAL LAND USE MILEAGE (BOTH SIDES OF TRACK)

DATA UNIQUE TO PARTICULAR SYSTEMS ARE NOTED ON SYSTEM SCHEMATICS



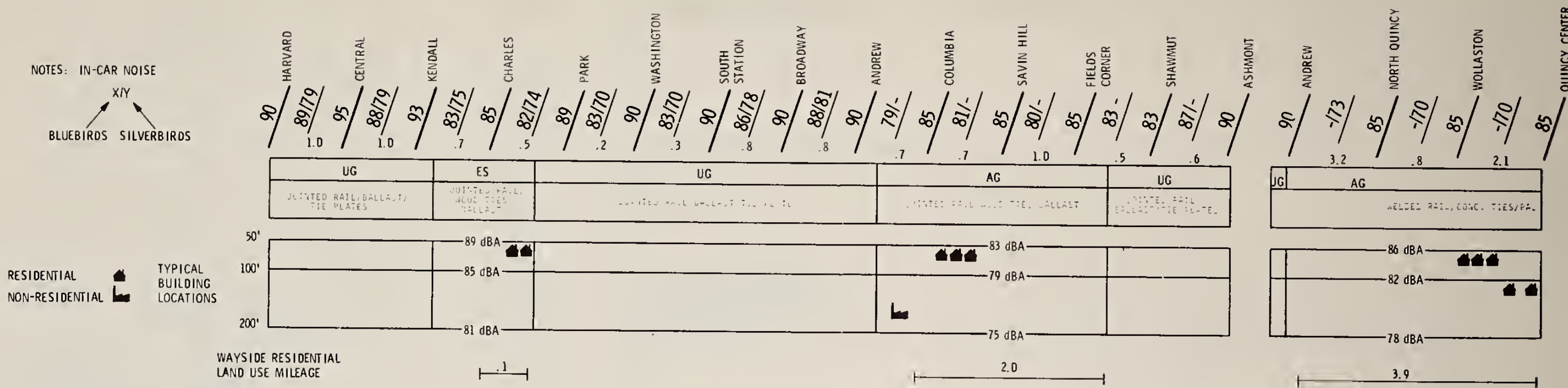



FIGURE A-2 MBTA SYSTEM, THE RED LINE

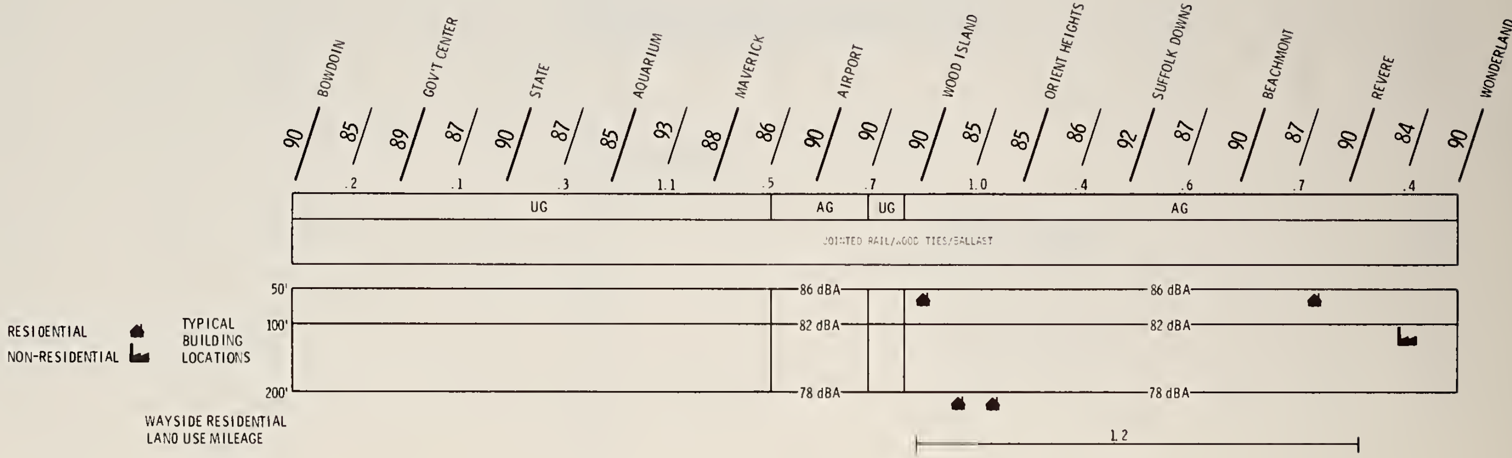



FIGURE A-3 MBTA SYSTEM, THE BLUE LINE

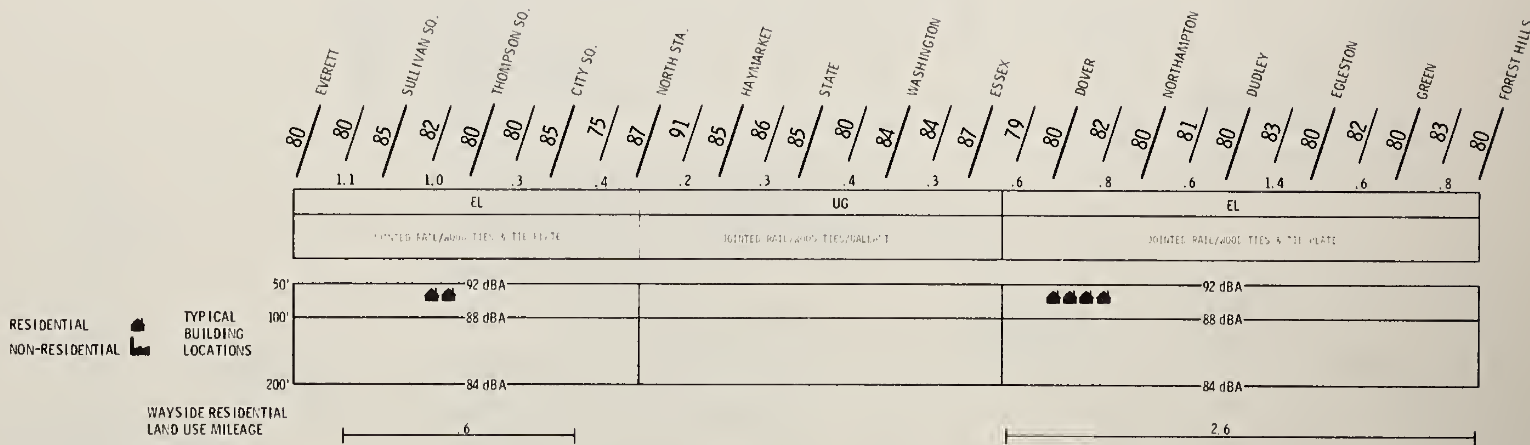



FIGURE A-4 MBTA SYSTEM, THE ORANGE LINE

TABLE A-2 MBTA IN-CAR NOISE SUMMARY

| | UNDERGROUND | ELEVATED STEEL | AT-GRADE (Jointed) | AT-GRADE (Welded) | BRIDGE |
|---|---|---|---|---|---|
| Blue Line Cars | 91 dBA | | 87 dBA | | |
| Orange Line Cars and Red Line Bluebirds | 87 dBA | 82 dBA | 80 dBA | | 80 dBA |
| Red Line Silverbirds | 78 dBA | | | 72 dBA | 71 dBA |

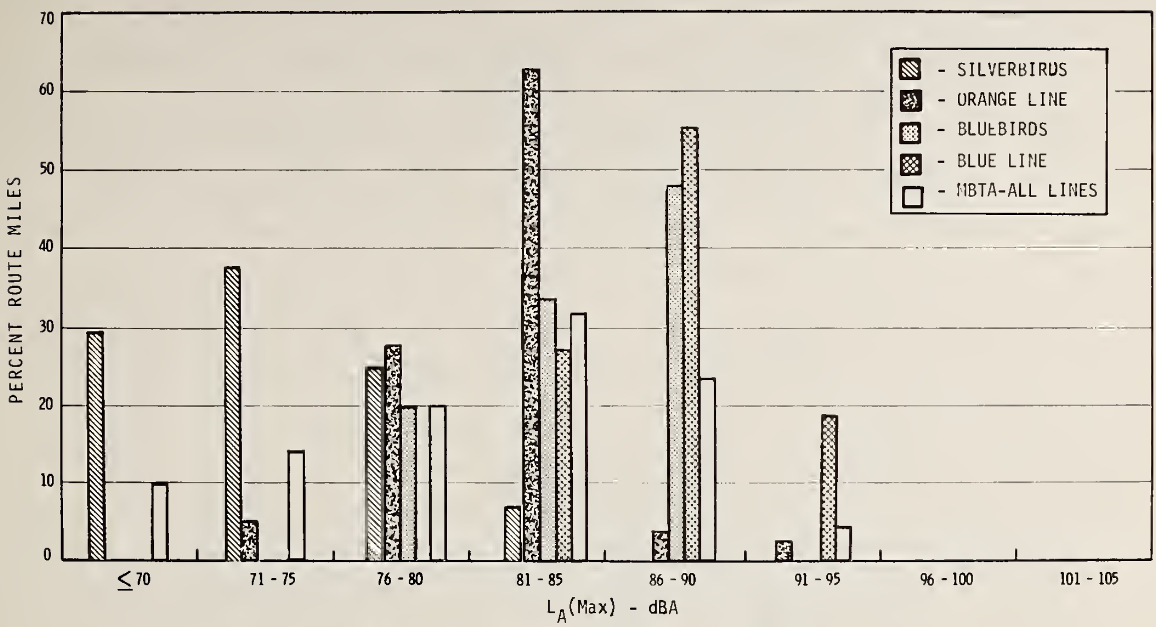



FIGURE A-5 MBTA SYSTEM, DISTRIBUTION OF IN-CAR PLATEAU NOISE LEVELS

These levels are as follows: South Shore Extension, 72.0 dBA; Orange Line, 79.5 dBA; Ashmont Line, 82.2 dBA; and Blue Line, 85.5 dBA. The equivalent levels from route to route vary as the ranges in $L_A$(Max) vary. By taking a ridership-weighted energy average of these route levels, one obtains a mean $L_{eq}$(R) of 79.0 dBA for the MBTA as a whole.

Based on the inter-station $L_{eq}$ as the noise level parameter, Figure A-6 shows a distribution of route mileage versus $L_{eq}$ for

the MBTA. Slightly less than half the route mileage is associated with inter-station track over which $L_{eq}$ levels between 80 and 95 dBA would exist. Figure A-6 also includes the individual routes on the MBTA. There were some obvious property and structure differences among the routes at the time noise measurements were made. It would be expected, for instance, that the lowest in-car levels would be found on the South Shore Extension since the Silverbirds run along this line. It is also reasonable to expect the Orange Line levels to be lower than both the Ashmont and Blue Line levels. Less than one-eighth of the Orange Line route-mileage was underground when measurements were taken; this contrasts with the Ashmont Line, with three-quarters of its track in subway, and the Blue Line, with more than one-third of its system below ground. The difference between in-car levels on the Ashmont Line and the Blue Line can be attributed primarily to the age of the respective cars. One-third of the Blue Line's 75-car fleet was 35 years old, and the remaining cars were all at least 20 years old. The Ashmont cars, on the other hand, were all only 10 to 12 years old.

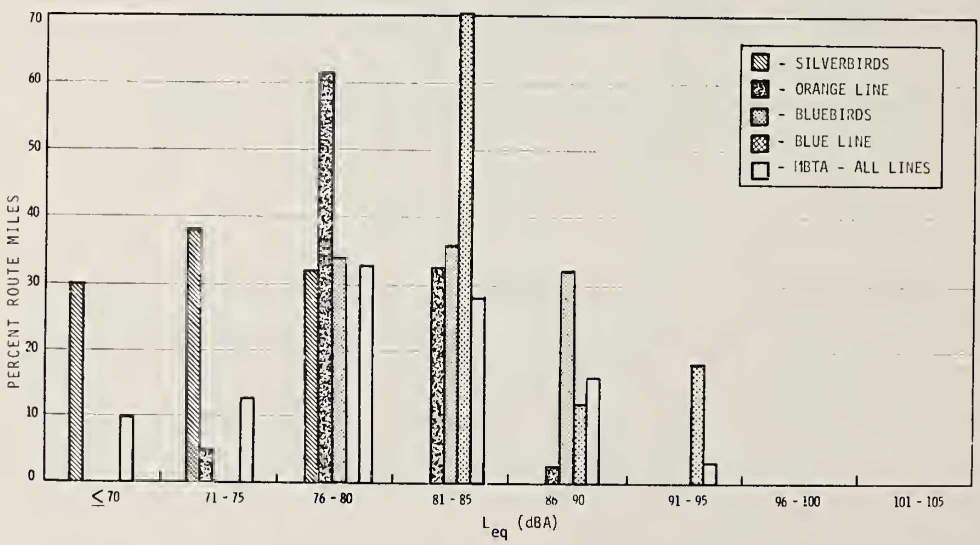



FIGURE A-6 MBTA SYSTEM, DISTRIBUTION OF IN-CAR EQUIVALENT SOUND LEVELS

### A.2.3 In-Car Noise Exposure

Figure A-7 represents an estimate of in-car noise exposure, giving the distribution of people-hours versus inter-station $L_{eq}$. Figure A-7 shows that about half of the MBTA ridership (patronage weighted by estimated trip times) is exposed to average in-car level of 81 dBA or greater.

### A.2.4 Comparison of MBTA In-Car $L_A$(Max) with APTA Guidelines

Figure A-8 shows a distribution of route mileage versus deviation in dBA from APTA guidelines. The graph indicates that for over 50 percent of the route mileage the in-car noise levels exceed the recommended APTA levels for new systems by more than six dBA.

## A.3 STATION NOISE

### A.3.1 $L_A$(Max) and $L_{eq}$

The noise levels at the various station platforms throughout the MBTA are decidedly more uniform than the in-transit car noise levels. With the exception of elevated stations on the southern branch of the Orange Line, all stations have average maximum arrival-departure sound levels between 83 and 93 dBA. It is worth noting that no clear structural demarcation exists in that range of noise levels (See Table A-3 for Station Noise Summary). The Orange Line elevated stations along the southern branch measure, or are inferred to be, 80 dBA. The distribution of the average maximum arrival-departure sound levels for the entire system is shown in Figure A-9. A similar system-wide distribution of transit stations versus the equivalent sound level based on 30-minute evaluation periods is shown in Figure A-10. The patterns in the two graphs are very similar. This is due to the fact that train arrivals and departures are the main determinant of both $L_A$(Max) and $L_{eq}$, and that transit car headway times do not vary much from route to route.

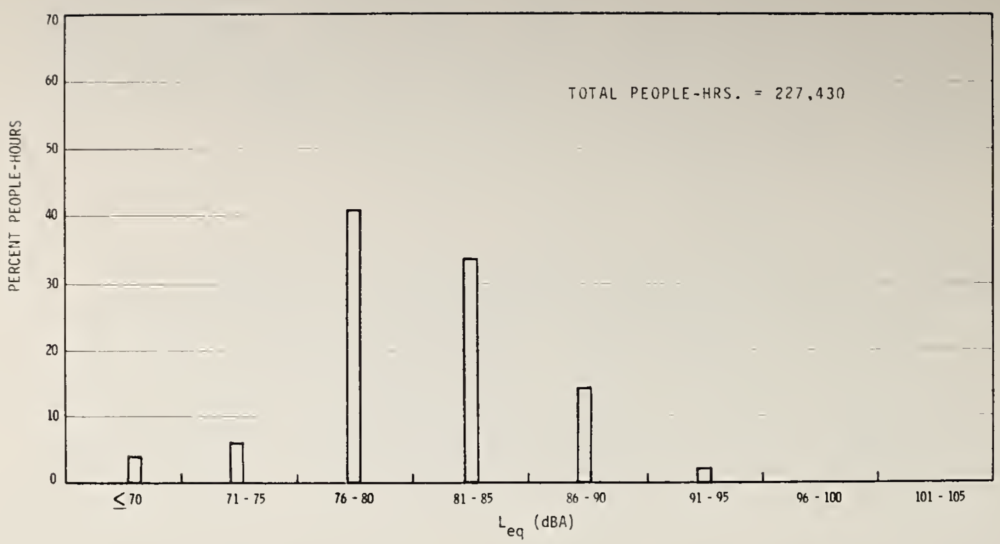



FIGURE A-7 MBTA SYSTEM, IN-CAR NOISE EXPOSURE

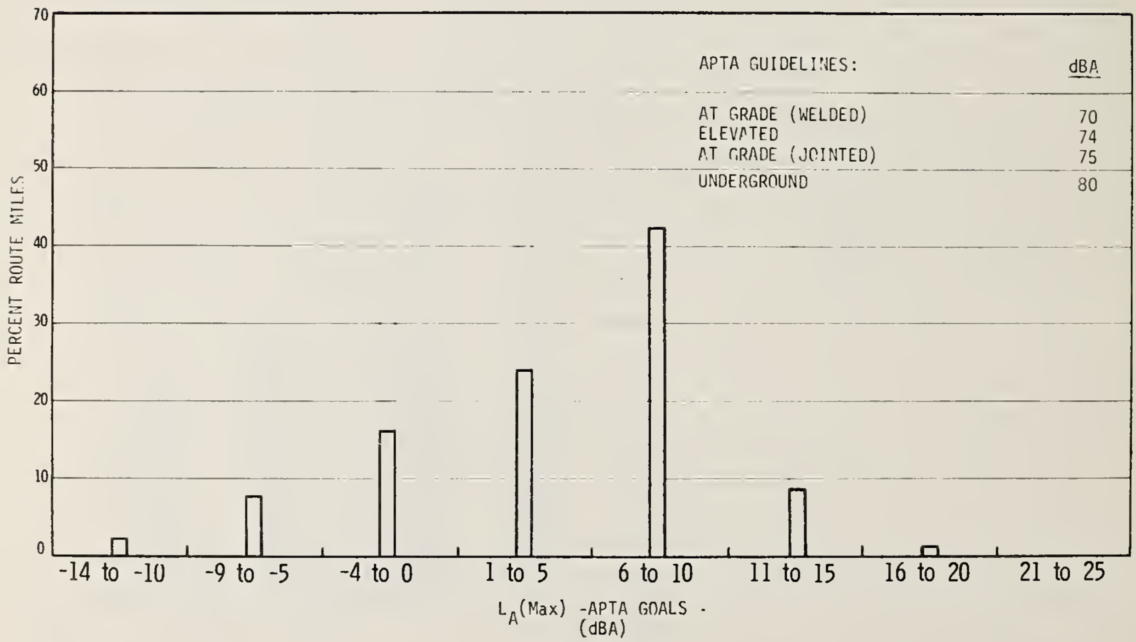



FIGURE A-8 MBTA SYSTEM, IN-CAR NOISE GUIDELINE COMPARISON

TABLE A-3 MBTA STATION NOISE SUMMARY

| | UNDERGROUND | ELEVATED STEEL | AT-GRADE (Jointed) | AT-GRADE (Welded) |
|---|---|---|---|---|
| Blue Line | 89 dBA | | 90 dBA | |
| Orange Line | 85 dBA | 82 dBA | | |
| Red Line | 91 dBA | 85 dBA | 85 dBA | 85 dBA |

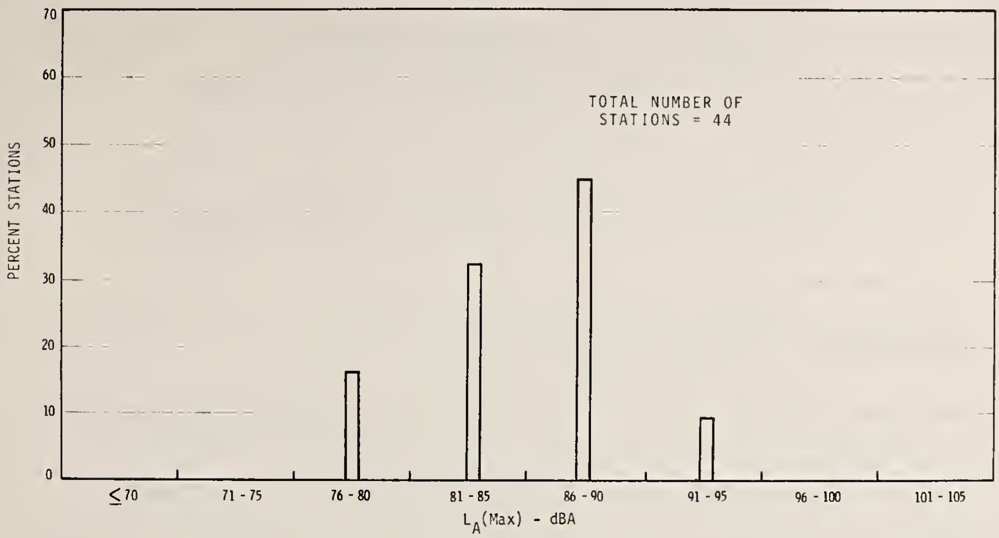



FIGURE A-9 MBTA SYSTEM, IN-STATION MAXIMUM NOISE LEVELS

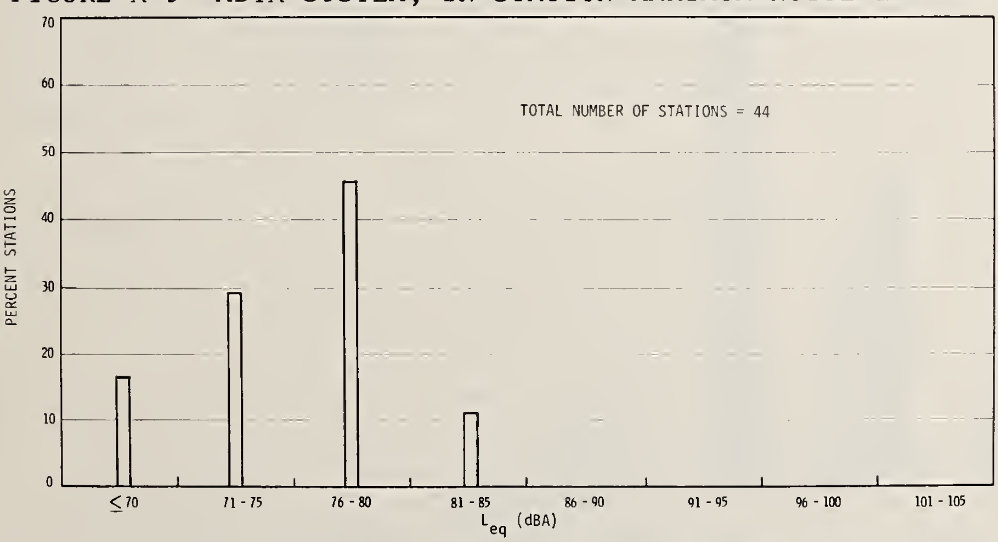



FIGURE A-10 MBTA SYSTEM, IN-STATION EQUIVALENT SOUND LEVELS

### A.3.2 In-Station Noise Exposure

Figure A-11 shows a distribution of patronage versus station $L_{eq}$ levels for the entire MBTA system. Well over 50 percent of MBTA passengers waiting on platforms experience $L_{eq}$ levels between 75 and 85 dBA. It must be kept in mind that the 50 percent is not distributed uniformly over all stations; instead, it can be attributed to stations on particular lines. That is, the ridership information for each station was used to develop the distribution shown in Figure A-11.

The elevated stations on the Orange Line seem to dominate the low end of $L_{eq}$ values for the MBTA, the range along the route being <70 to 80 dBA. The Red and Blue Lines have similar station noise levels, although the average waiting time is different (3.75 minutes for the Red Line and five minutes for the Blue Line).

### A.3.3 Comparison of MBTA Station $L_A$(Max) with APTA Guidelines

In Figure A-12 the distribution of percentage of stations versus deviation in dBA from APTA guidelines indicates that 70 percent of the MBTA system exceeds the recommended maximum station platform noise levels for new systems by at least six dBA.

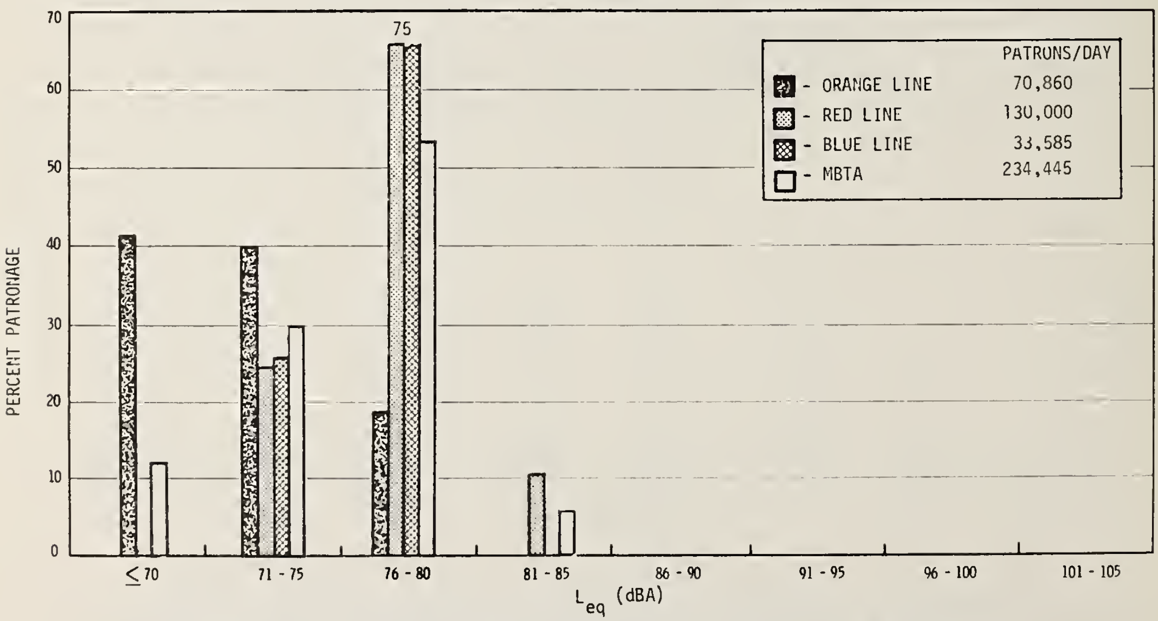



FIGURE A-11 MBTA SYSTEM, IN-STATION NOISE EXPOSURE

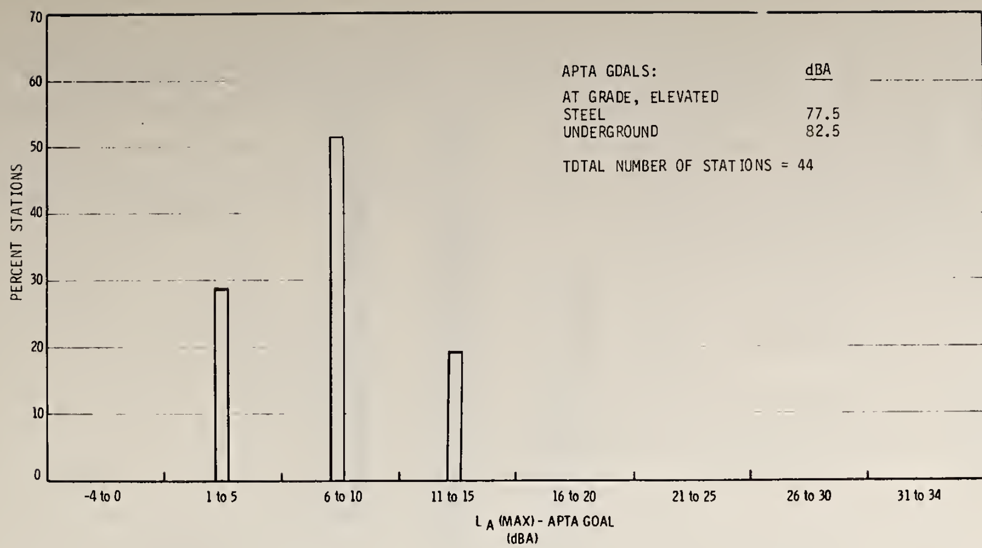



FIGURE A-12 MBTA SYSTEM, IN-STATION NOISE GUIDELINE COMPARISON

## A.4 MBTA WAYSIDE NOISE

### A.4.1 $L_A$(Max)

The A-weighted average maximum pass-by levels, $L_A$(Max), at 15 m (50 ft) from the near track center-line range from 83 to 92 dBA. Figures A-13 and A-14 show the distribution of the residential and non-residential wayside mileage by $L_A$(Max) level for each of the three MBTA lines.

The highest noise levels, 89 and 92 dBA, occur along the elevated steel segments of the Red and Orange Lines, respectively. These high wayside sound levels are particulary significant due to the proximity of buildings to the elevated track (See Figures A-2, A-3, and A-4). Note that the $L_A$(Max) on the Red Line is 3 dBA lower than the levels observed on the Orange Line, even though the trains' average speed is higher, 53 km/h (33 mph) as opposed to 37 km/h (23 mph). The newer equipment on the Red Line is considered to be the primary reason for this.

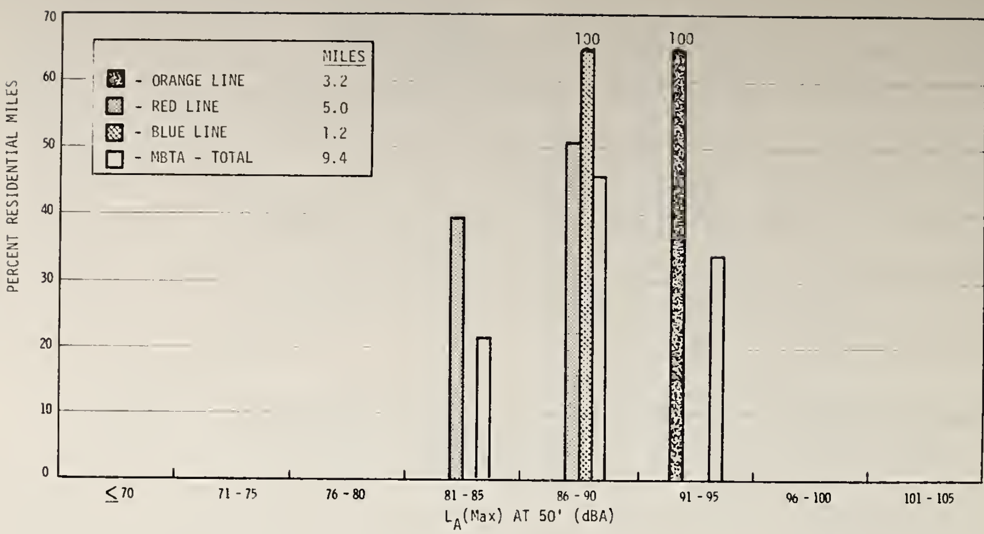



FIGURE A-13 MBTA SYSTEM, DISTRIBUTION OF RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

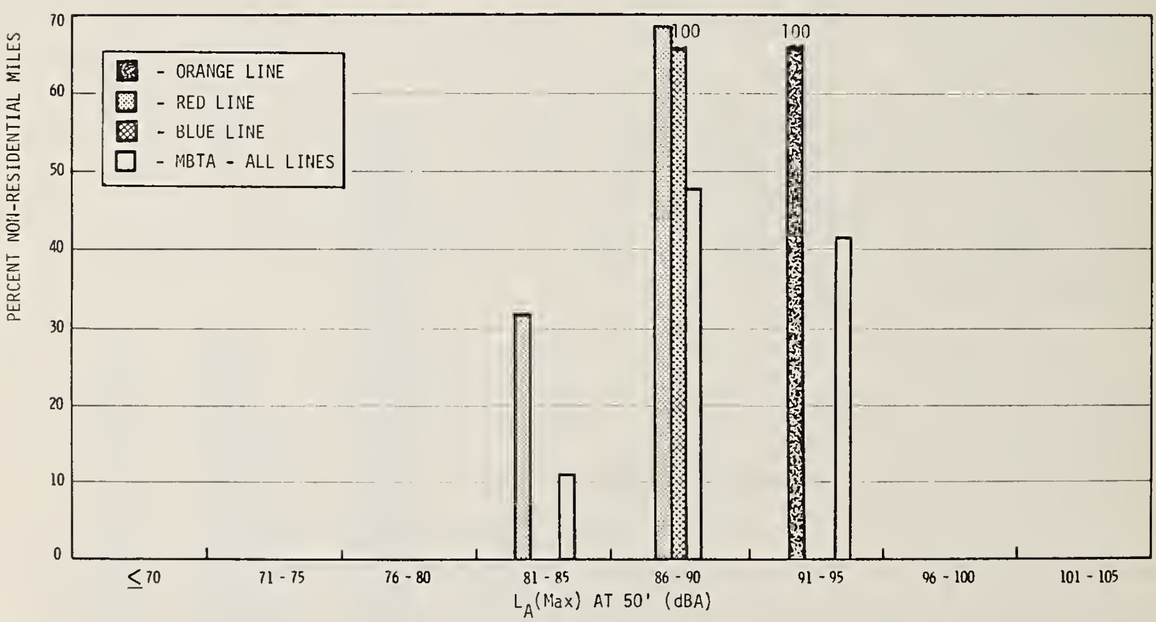



FIGURE A-14 MBTA SYSTEM, DISTRIBUTION OF NON-RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

The remaining aboveground track is at-grade on the Red and Blue Lines, where lower noise levels are observed. Most of the wayside is exposed to an $L_A$(Max) level of 86 dBA, with a level of 83 dBA recorded on the Ashmont Branch of the Red Line. Two important features can be observed. The at-grade track comprised of jointed rail on the Blue Line has a higher (3 dBA) $L_A$(Max) level than similar segments on the Red Line. As above, the newer Red Line cars are considered to be the primary reason for this. Secondly, the $L_A$(Max) level observed on the continuously welded rail segments of the Red Line (South Shore Extension) is 3 dBA higher than the level noticed on the jointed segments (Ashmont Branch). However, train speeds are considerably higher on the South Shore Extension, and, at the time the noise measurement were made, more wheel flats were noticeable on the Silverbirds than on the Bluebirds.

### A.4.2 $L_{dn}$(Trains)

Wayside equivalent day-night sound levels resulting only from train pass-bys, $L_{dn}$ (Trains), are shown in Figure A-15. The $L_{dn}$ (Trains) level is based on the pattern of wayside $L_A$(Max) and also reflects the number and duration of train pass-bys.

The highest $L_{dn}$ (Trains) levels are observed at the elevated steel segments (77 and 74 dBA), with lower levels on at-grade sections. The effects of increased train pass-bys can be seen by examining the Red Line. An $L_{dn}$ (Trains) level of 70 dBA is observed on at-grade segments where the number of train pass-bys are doubled. This level is two to four dBA higher than levels observed on other Red Line, at-grade track sections.

### A.4.3 $L_{dn}$(Ambient)

The average $L_{dn}$(Ambient) levels resulting from all noise sources other than train pass-by noise, which are used to determine the noise environment of wayside communities, are 61.6, 64.6, 63.8 and 63.8 dBA, respectively, for the Blue, Orange, and Red Lines,

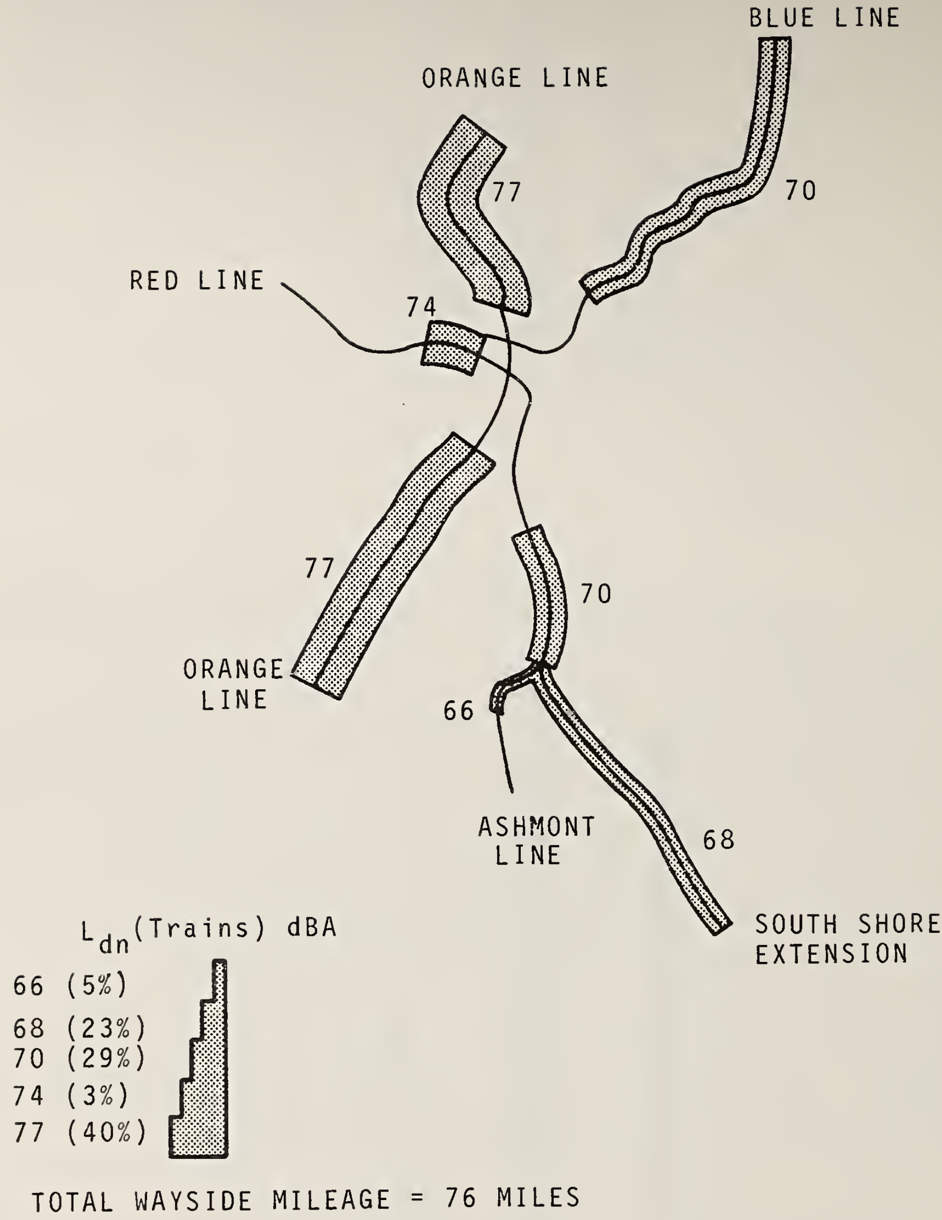



FIGURE A-15 MBTA, WAYSIDE $L_{dn}$ (TRAINS) LEVELS

and the total MBTA system.

### A.4.4 Relative $L_{dn}$

The distribution of Relative $L_{dn}$, the difference between $L_{dn}$ (from all noise sources) and $L_{dn}$(Ambient), as shown in Figure A-16, reflects both the pattern of $L_{dn}$(Trains), Figure A-15, and the distribution of the $L_{dn}$(Ambient) levels described above.

The Relative $L_{dn}$ levels range from one to 16 dBA on the total MBTA system, with a mean level of 8.7 dBA. The ranges and means for the component routes follow:

| | | |
|---|---|---|
| Red Line | 1 - 11 dBA; | 6.0 dBA |
| Blue Line | 7 - 13 dBA; | 9.2 dBA |
| Orange Line | 7 - 16 dBA; | 12.8 dBA |

Low Relative $L_{dn}$ levels (one to five dBA) are recorded exclusively along the Red Line and primarily adjacent to at-grade track.

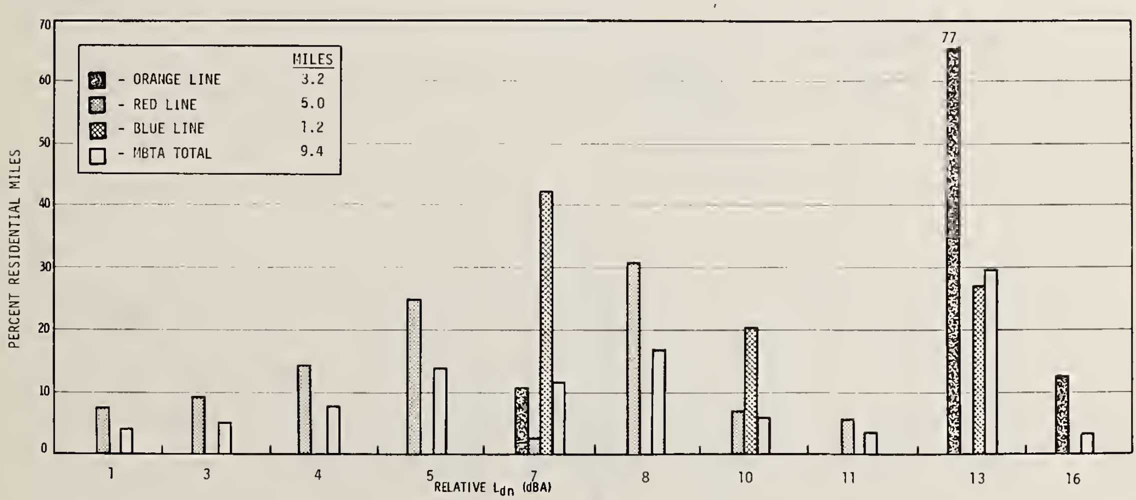



FIGURE A-16 MBTA SYSTEM, DISTRIBUTION OF WAYSIDE RELATIVE $L_{dn}$

Approximately 29 percent of the MBTA residential mileage is exposed to these levels. In these communities, medium (64 dBA) or high (71 dBA) $L_{dn}$(Ambient) levels are combined with medium (66-70 dBA) $L_{dn}$(Trains) levels. Relative $L_{dn}$ levels of seven to ten dBA can be found adjacent to all three MBTA routes, primarily on at-grade segments. Nearly 34 percent of the total residential mileage experiences these levels. In the at-grade communities, medium ambient levels (61 and 64 dBA) are combined with medium trains levels (68 and 70 dBA). The communities adjacent to elevated steel track have a high $L_{dn}$(Ambient) level (71 dBA) and a high $L_{dn}$ (Trains) level (77 dBA).

The remaining mileage, 37 percent, is exposed to Relative $L_{dn}$ levels greater than ten dBA. Nearly 83 percent of these communities are adjacent to the elevated steel sections of the Orange Line. Here medium ambient levels (61 and 64 dBA) combine with a high trains level (77 dBA). In the communities abutting at-grade track, a low $L_{dn}$(Ambient) level (58 dBA) combines with medium $L_{dn}$(Trains) levels (68 and 70 dBA).

### A.4.5 Wayside Exposure

The total population residing within the 60-m (200-ft) corridor along aboveground segments of the MBTA is estimated to be approximately 5750. Nearly 93 percent of this population has residences adjacent to the Red and Orange Line rights-of-way. The remainder lives in communities along the Blue Line, which passes through considerably less densely populated areas.

Figure A-17 shows the percent population against Relative $L_{dn}$. Approximately 49 percent of the population experiences low levels, less than or equal to five dBA. At the other extreme, nearly 25 percent of the wayside population resides in communities where Relative $L_{dn}$ levels are greater than ten dBA.

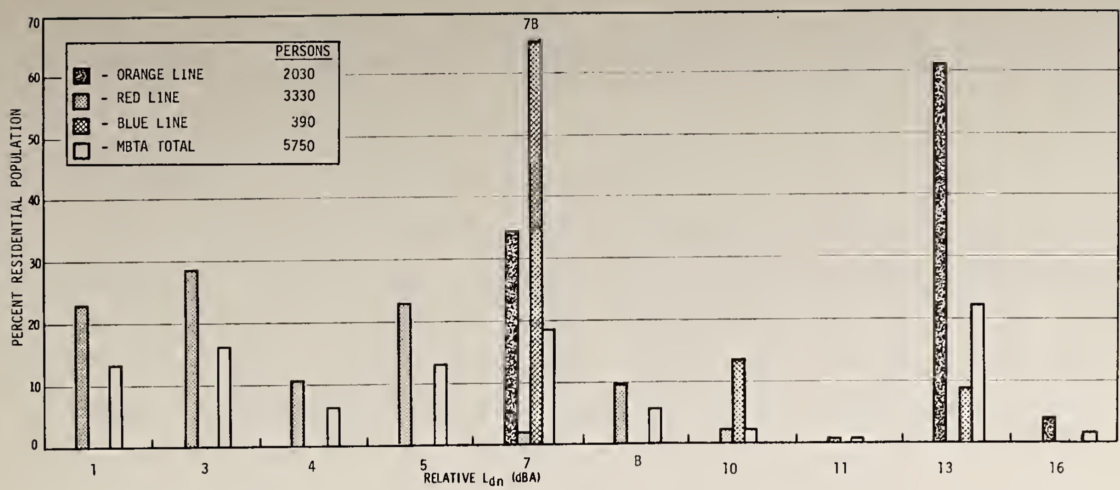



FIGURE A-17 MBTA SYSTEM, WAYSIDE NOISE EXPOSURE

### A.4.6 Comparison of MBTA Wayside $L_A$(Max) with APTA Guidelines

Figure A-18 shows the distribution of wayside $L_A$(Max) at 15 m (50 ft) relative to the APTA goals for residential and non-residential areas abutting the rail right-of-way. While all of the MBTA wayside $L_A$(Max) levels exceed the APTA goals, it is interesting to note that 25 percent of the residential, and 59 percent of the non-residential areas have $L_A$(Max) levels within ten dBA of the APTA goals for new systems.

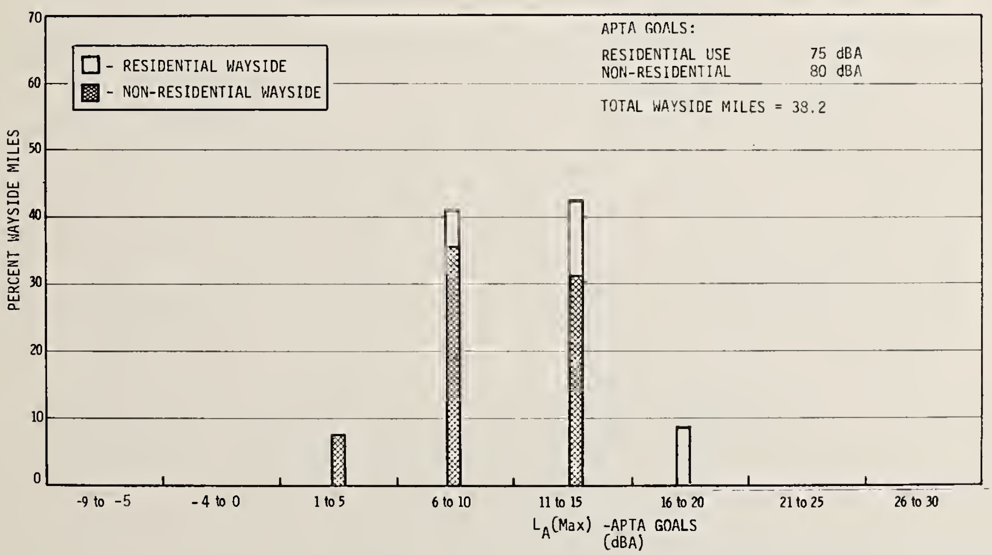



FIGURE A-18 MBTA SYSTEM, WAYSIDE NOISE GUIDELINE COMPARISON

# APPENDIX B - URBAN RAIL NOISE ASSESSMENT OF SEPTA SYSTEMS

## B.1 SYSTEM DESCRIPTION (See Table B-1)

The Southeastern Pennsylvania Transportation Authority (SEPTA) operates two rapid transit routes in the city of Philadelphia, the Broad Street Subway and the Market-Frankford Line (See Figure B-1). Of the 23.6 right-of-way miles (38 km) on the system, 60 percent is subway, 35 percent is steel elevated track, and five percent is grade level track.

All rail is jointed on the SEPTA system except at those locations where rail has been replaced, in which case new field-welded rail has been installed. Wood ties in ballast are used on at-grade and elevated sections. On the elevated sections, the ballast is supported by a concrete sub-base on a steel elevated structure. Along underground track on the Market-Frankford Line, half ties in concrete support the rail, while on the Broad Street Subway the rail is set on tie plates which are resiliently mounted on top of pads on a concrete base.

### B.1.1 Stations

There are 25 stations on the Broad Street Line. The most prevalent station configurations are as follows: two-track, center platform; four-track, two center platforms; and four-track, two side platforms. The latter are skip stop stations for express trains which operate during peak hours. All visible station surfaces are of hard masonry or ceramic tile finish. Except for the tunnel ceiling at City Hall Station, where perforated steel sheets with approximately one inch of fiberglass backing are used, no noise control treatment has been applied in the stations.

There are 28 stations on the Market-Frankford Line. Most are two-track stations with side platforms. The surface stations are constructed of wood or concrete and are covered by open-sided enclosures. The design of the subway stations reflects the date of their construction, 1907. The stations are essentially all

TABLE B-1 SEPTA SYSTEM SUMMARY (1 OF 2)

| | MARKET-FRANKFORD | BROAD ST./RIDGE SPUR | Total |
|---|---|---|---|
| A. ROUTE PHYSICAL | | | |
| 1. Length | 12.7 Miles | 9.8/1.2 Miles | 23.7 Miles |
| 2. Track Type | Jointed Rail: Concrete Sub-base, Wood Ties in Concrete, Ballast and Ties. | Jointed Rail: Wood Ties in Concrete, Rail on Tie Plate, Ballast and Tie. | |
| 3. Track Structure Mileage | | | |
| a. Underground | 3.8 Miles | 9.3/1.2 Miles | 14.3 Miles |
| b. Steel EL | 8.3 Miles | | 8.3 Miles |
| c. Concrete EL | | | |
| d. At-Grade | .6 Miles | .5 Miles | 1.1 Miles |
| e. In-Cut | | | |
| 4. Number of Stations | 28 | 22/3 | 53 |
| B. VEHICLES | | | |
| 1. Year Manufactured | 1960 | 1928,1938/1936 | |
| 2. Number in Service | 273 | 150, 50/ 25 | 498 |
| 3. Acoustical Treatment | No | No / No | No |
| C. SYSTEM SCHEDULING | | | |
| 1. Running Time | 40 Minutes | 35 Minutes | |
| 2. Average Running Speed | 45 mph | 19 mph | |

TABLE B-1 SEPTA SYSTEM SUMMARY (2 OF 2)

| | MARKET-FRANKFORD | BROAD ST./RIDGE SPUR | Total |
|---|---|---|---|
| D. POPULATION DATA | | | |
| 1. Daily Ridership | 205,860/day | 131,258/day | 337,118/day |
| 2. Wayside Population Density (Mean) | 31,770/sq. mi. | 17,500/sq. mi. | 31,400/sq. mi. |
| 3. Wayside Population Within 200 ft. | 5390 | 80 | 5470 |
| 4. Residential Land Use (Length-% of Total Wayside) | 5.7 Miles (30.1%) | .2 Miles (.8%) | 5.9 Miles (30.9%) |
| E. IN-CAR SOUND LEVELS | Single Car/Double Car | | |
| 1. Average Inter-Station $L_A$(Max) | 81.7/79.8 dBA | 91.3 dBA | 86.1 dBA |
| 2. $L_A$(Max) Standard Dev. | 4.41/4.32 dBA | 1.85 dBA | 5.86 dBA |
| 3. $L_{eq}$(R) | 79.5/77.6 dBA | 89.1 dBA | 81.1 dBA |
| F. IN-STATION SOUND LEVELS | | | |
| 1. Average Station $L_A$(Max) | 89.1 dBA | 93.5 dBA | 91.6 dBA |
| 1.5 Range of $L_A$(Max) | 80-98 dBA | 86-98 dBA | 80-98 dBA |
| 2. Average Station $L_{eq}$ | 78.9 dBA | 81.7 dBA | 80.2 dBA |
| G. WAYSIDE COMMUNITY SOUND LEVELS | | | |
| 1. Average $L_A$(Max)@ 50' | 86.6 dBA | 76.0 dBA | 86.3 dBA |
| 1.5 $L_A$(Max)Range @ 50' | 78-89 dBA | 76 dBA | 76-89 dBA |
| 2. Average $L_{dn}$(Trains) | 73.2 dBA | 65.0 dBA | 72.9 dBA |
| 3. Average $L_{dn}$(Ambient) | 66.6 dBA | 64.4 dBA | 66.6 dBA |
| 4. Average Relative $L_{dn}$ | 7.8 dBA | 3.0 dBA | 7.6 dBA |


FIGURE B-1  SEPTA RAIL TRANSIT LINES

masonry in construction and have large expanses of wall, and floor surfaces of concrete, terrazo, glazed brick, and ceramic tiles. There is no acoustical treatment in any of the stations.

### B.1.2 Transit Fleet

The 225 vehicles in use in the Broad Street system consist of 150 Brill cars purchased in 1928 and an additional 50 cars constructed in 1938. The remaining 25 Brill cars entered the system in 1936 to operate exclusively on the Ridge Avenue spur and are called Bridge cars. There are no air-conditioned or acoustically treated vehicles in use in the Broad Street Subway. The Brill cars seat 67 to 71 passengers, and are 21 m (67-1/2 ft) long.

The 273 transit cars in use on the Market-Frankford Line were built by Budd in 1960. They are 17 m (54-1/3 ft) long and seat 54 passengers. The cars have no specific acoustical treatment, although the thermal insulation normally applied to the car body has some incidental acoustical effect. During the acoustic testing period, Acousta Flex wheels were installed on one car for evaluation purposes. These wheels virtually eliminated the wheel screech normally generated by all-steel wheels in conjunction with rail on curves. Resilient wheels and other wheel-rail noise reduction mechanisms are currently being tested on the SEPTA system.

### B.1.3 Route Descriptions (See Figures B-2, B-3)

The Broad Street Subway extends in a north-south direction through Philadelphia. Constructed in 1928, the line is approximately 15.7 km (9.8 mi) long. The track along the route is entirely in a cut-and-cover subway except for the Fern Rock Station, the northern terminal, which is at-grade. City Hall, a major central station, is an interchange with the Market-Frankford Line and the Subway-Surface Line (light rail). The Broad Street Subway passes below the other two systems. At Fairmont Station there is a 1.9-km (1.2-mi) extension of the Broad Street Subway, known as the Ridge

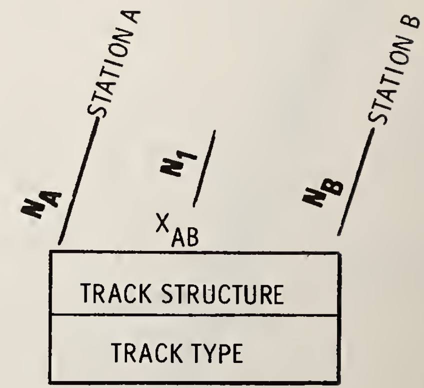
# LEGEND FOR FIGURES B-2 AND B-3

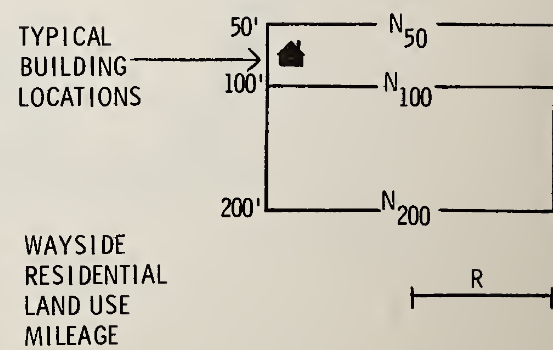
TRACK STRUCTURE

| | | |
|---|---|---|
| ES | = | ELEVATED STEEL |
| EE | = | ELEVATED EMBANKMENT |
| UG | = | UNDERGROUND |
| CV | = | CONCRETE VIADUCT |
| IC | = | IN CUT |
| AG | = | AT GRADE |
| MS | = | MEDIAN STRIP |
| EC | = | ELEVATED CONCRETE |
| A | = | AERIAL |

| | | |
|---|---|---|
| $X_{AB}$ | = | INTERSTATION DISTANCE (MILES) |
| $N_A/N_B$ | = | STATION NOISE AT STATION A/B (dBA) |
| $N_i$ | = | IN-CAR NOISE (dBA) |
| $N_{50}$ | = | WAYSIDE NOISE AT 50 FEET (dBA) |
| $N_{100}$ | = | WAYSIDE NOISE AT 100 FEET (dBA) |
| $N_{200}$ | = | WAYSIDE NOISE AT 200 FEET (dBA) |
| R | = | WAYSIDE RESIDENTIAL LAND USE MILEAGE (BOTH SIDES OF TRACK) |

DATA UNIQUE TO PARTICULAR SYSTEMS ARE NOTED ON SYSTEM SCHEMATICS



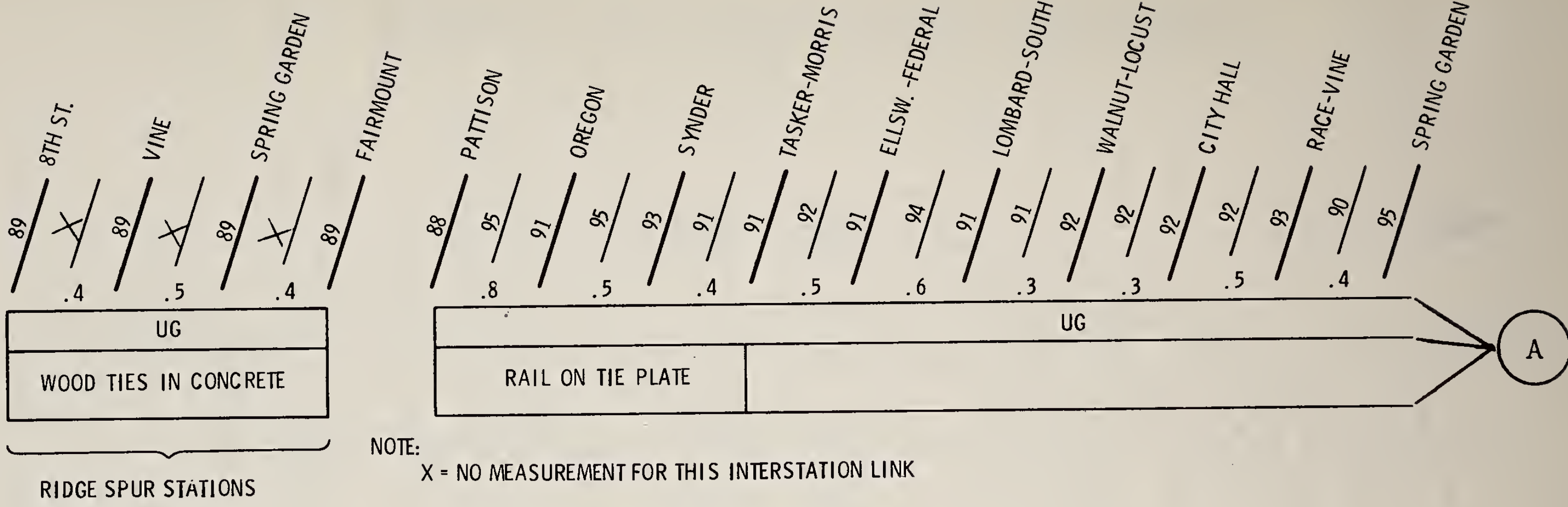



FIGURE B-2A SEPTA SYSTEM, BROAD STREET LINE

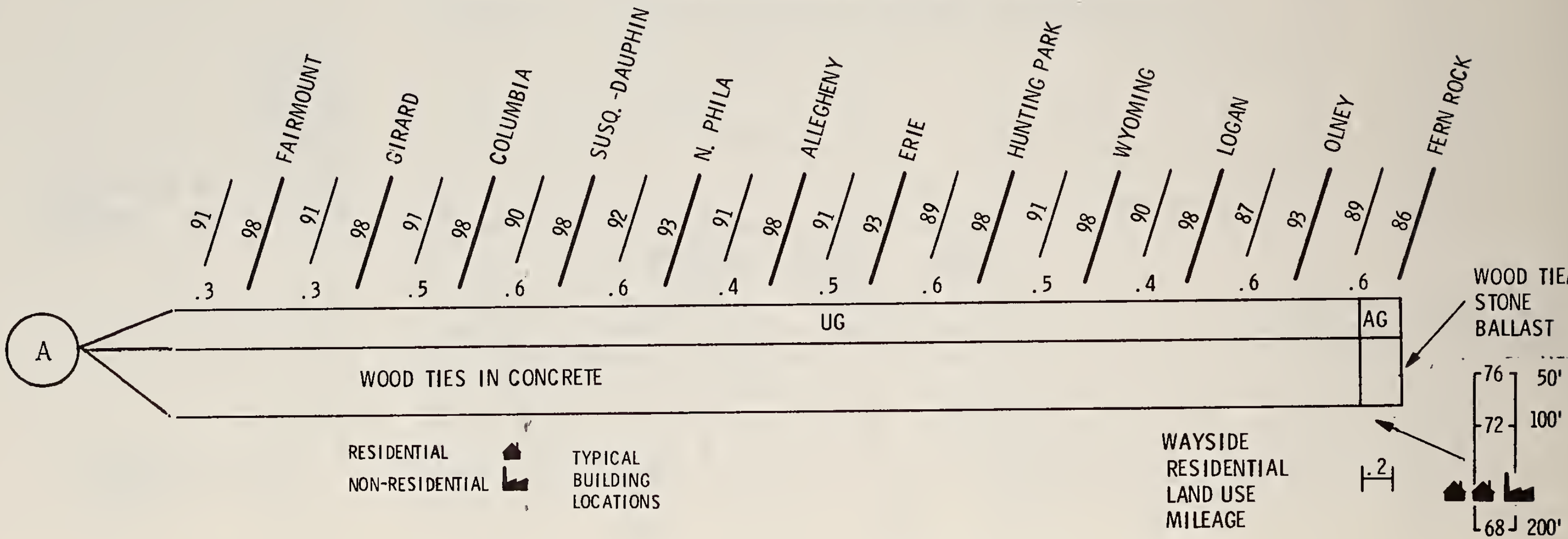



FIGURE B-2B SEPTA SYSTEM, BROAD STREET LINE

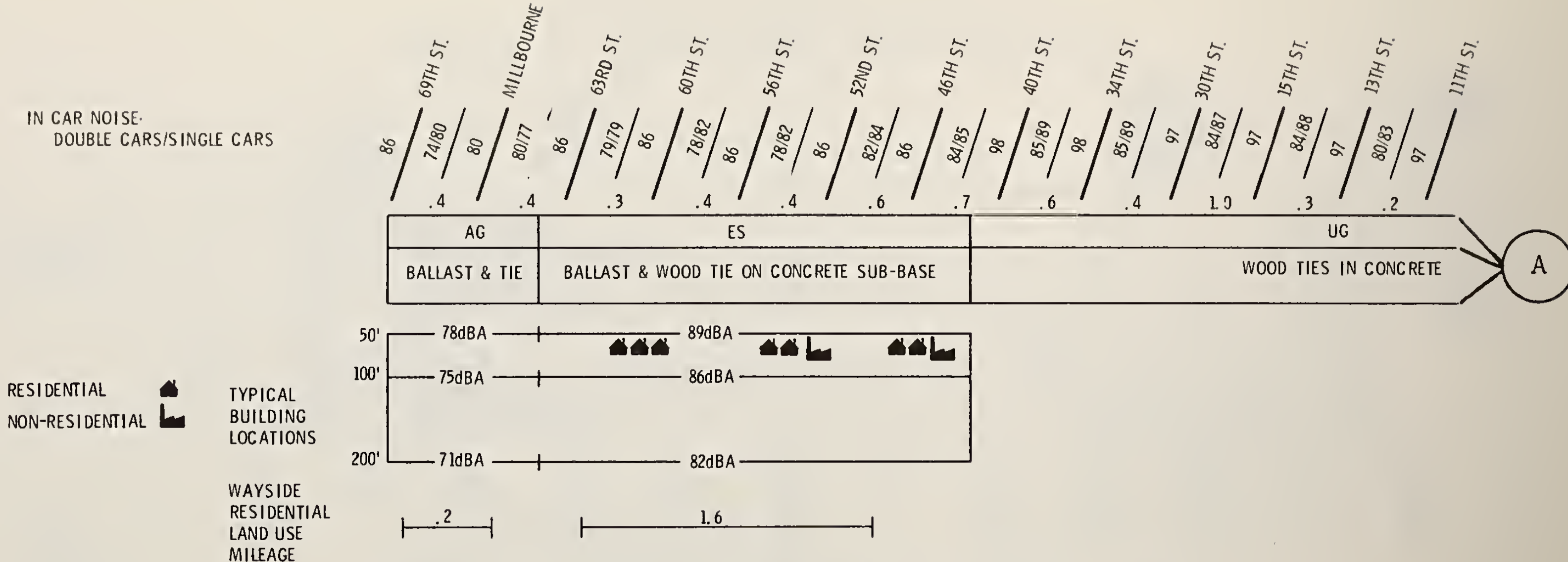



FIGURE B-3A SEPTA SYSTEM, MARKET-FRANKFORD LINE

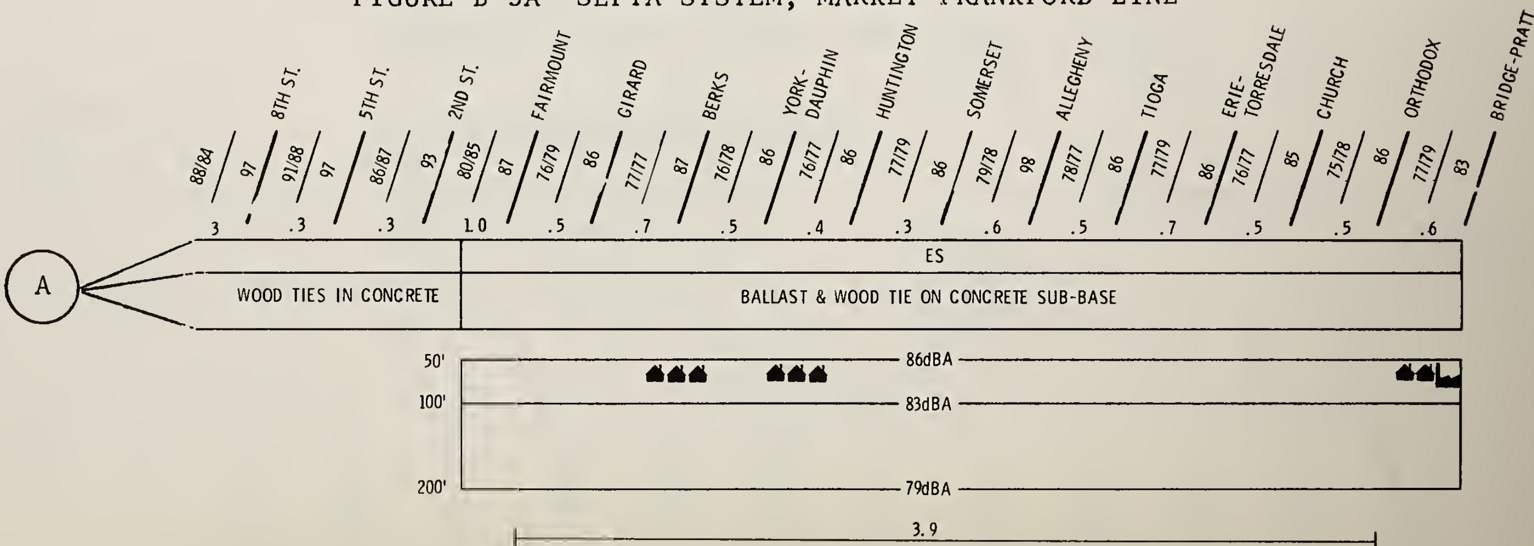



FIGURE B-3B SEPTA SYSTEM, MARKET-FRANKFORD LINE

Spur, which runs south-east to the Eighth Street Station on the Market-Frankford Line.

The Broad Street Line is made up entirely of tangent track except at the Fern Rock Tunnel entrance and at City Hall Station, where there are curved segments.

Running time on the Broad Street Line is 35 minutes, at an average train speed of 30 km/h (19 mph). Headways range from three minutes during rush hour to 30 minutes from 1 A.M. to 5 A.M. Train lengths vary from three to six cars per train.

The Market-Frankford Line extends for 20.3 km (12.7 mi) from Upper Darby, a suburb of Philadlephia, along Market Street to the Frankford area of North Philadelphia. This route is divided into two segments. The first segment runs from the at-grade terminal in Upper Darby at 69th Street, onto the steel elevated structure above Market Street between 63rd and 46th Streets, and then through the subway, beneath Market Street, between 40th Street and 2nd Street. The second segment leaves the subway and becomes elevated again over Front Street. At the time of the noise measurements, the line between Front Street, just north of Market Street, and the northern terminal at Bridge-Pratt was elevated. When the Delaware Expressway was constructed, the line was relocated to follow the expressway route, which curves westward approximately one block from Front Street. Here the track structure was integrated into the highway structure, but it returns to a separate steel elevated steel structure again just south of the Girard Station. North of Bridge-Pratt, the line descends to grade into a reversing loop.

Noise singularities on the Market-Frankford Line include wheel squeal and severe joint impact. There are numerous locations on the line where wheel screech is generated: the 69th Street reversing loop, entering and leaving the 69th St. terminal, between the Milbourne and 63rd Street Stations, entering the subway east of 46th Street, north of 2nd Street, just prior to leaving the subway, north of York-Dauphin Station where the line joins Kensington Avenue, and south of Church Street Station.

The total running time of the Market-Frankford Line is 40 minutes. The transit cars travel at a speed of approximately 72 km/h (45 mph), although the speed was restricted to 32 km/h (20 mph) between Second and Bridge Streets at the time of the noise measurements, due to maintenance. Headways vary from three minutes at rush hour to 30 minutes for nighttime service from 1 A.M. to 5 A.M. Train lengths range from three to six cars per train.

## B.2 IN-CAR NOISE

### B.2.1 $L_A$(Max)

In-car noise plateau levels represented by the in-car $L_A$(Max), on the Market-Frankford Line of SEPTA vary according to type of track and type of car -- either single or double, as summarized in Table B-2. Speed plays a secondary role as a determinant of in-car noise.

TABLE B-2 SEPTA IN-CAR NOISE SUMMARY

| | UNDERGROUND | ELEVATED STEEL | AT-GRADE JOINTED |
|---|---|---|---|
| Market-Frankford Single Cars | 87 dBA | 80 dBA | 80 dBA |
| Market-Frankford Double Cars | 85 dBA | 78 dBA | 74 dBA |
| Broad St. Subway | 91 dBA | | 89 dBA |

The distribution of route miles at various in-car $L_A$(Max) levels in Figure B-4 reflects the differences in in-car noise on the two SEPTA lines. The lowest in-car noise levels are in double cars operating on the elevated sections of the Market-Frankford Line. The double cars are probably quieter because they share equipment when operated jointly. The majority of route mileage on the Market-Frankford Line falls in the 76 to 80 dBA range, representing sections of elevated steel track. The more de-

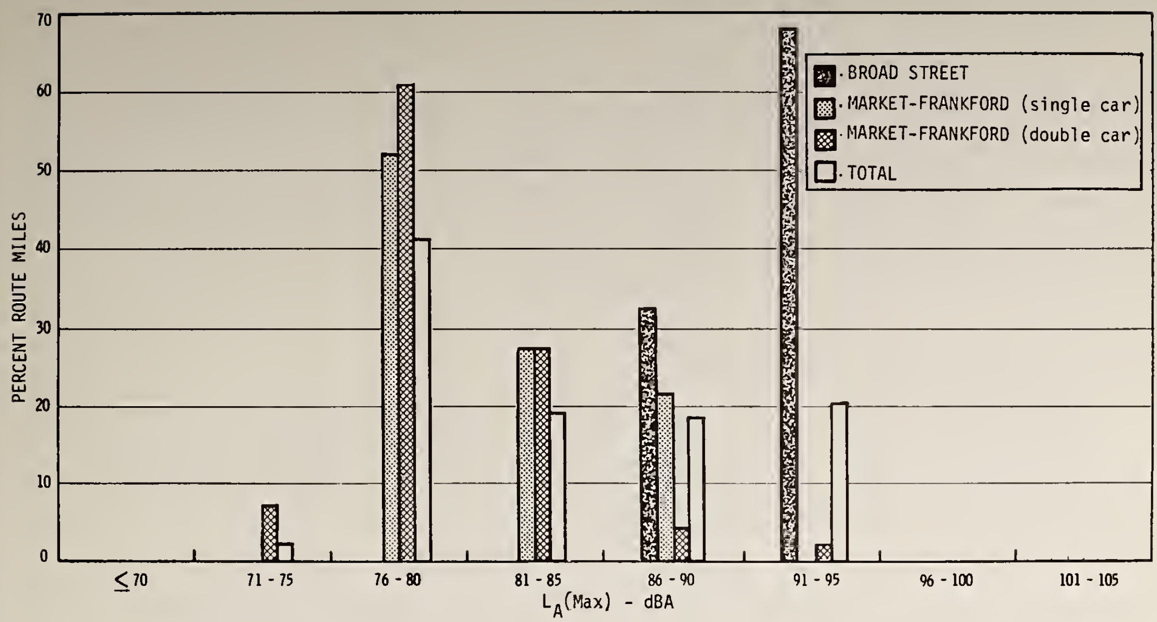



FIGURE B-4 SEPTA SYSTEM, DISTRIBUTION OF IN-CAR PLATEAU NOISE LEVELS

tailed data in Figure B-3 shows the effect of speed on $L_A$(Max). Noise levels on sections of elevated track north of Second Street are slightly lower due to speed restrictions which were in effect at the time noise measurements were taken. In-car sound levels are highest along underground sections, with double cars again averaging slightly lower than single cars. The older cars of the Broad Street Subway have higher $L_A$(Max) than those of the Market-Frankford Line for all types of track. Most of the Broad Street Line is underground and is characterized by in-car $L_A$(Max) of over 90 dBA, the highest on the SEPTA system (See Figure B-2).

### B.2.2 In-Car Equivalent Noise Levels

Route equivalent noise levels, $L_{eq}$(R), characterizing the in-car noise levels on the SEPTA system vary as the ranges in $L_A$(Max) vary. The $L_{eq}$(R) levels are 89 dBA for the Broad Street Subway, and 83 and 80 dBA for the Market-Frankford Line single

and double cars, respectively.

The distribution of route miles versus inter-station $L_{eq}$ is shown in Figure B-5. This distribution, like the distribution of $L_A$(Max) from which it was derived (Figure B-4), reflects the track structure, car type, and speed differences discussed above. For the entire SEPTA system, 54 percent of the route mileage is characterized by in-car $L_{eq}$ of 80 to 95 dBA.

### B.2.3 In-Car Noise Exposure

Figure B-6 represents an estimate of in-car exposure for the entire SEPTA system, by aggregating the distributions of people-hours versus inter-station $L_{eq}$ for all lines of the system. Approximately two-thirds of the ridership on the SEPTA system experiences an $L_{eq}$ greater than 81 dBA. If accurate average trip times for the system had been available for this analysis, one could specify the average time exposed to these $L_{eq}$ levels and the total number of patrons exposed at each level.

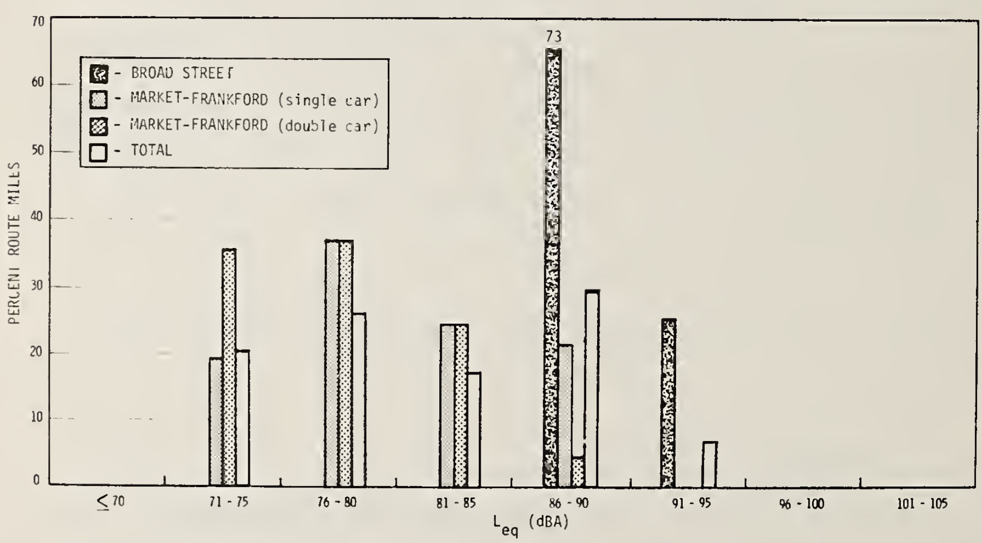



FIGURE B-5 SEPTA SYSTEM, DISTRIBUTION OF IN-CAR EQUIVALENT SOUND LEVELS

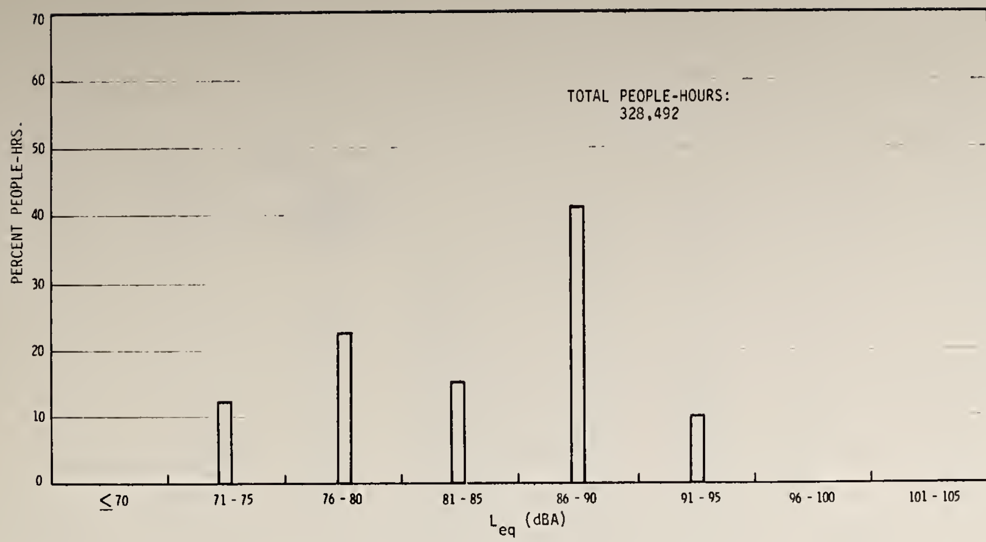



FIGURE B-6 SEPTA SYSTEM, IN-CAR NOISE EXPOSURE

### B.2.4 Comparison of SEPTA In-Car $L_A$(Max) with APTA Guidelines

Figure B-7 shows the distribution of route mileage versus the deviation in in-car $L_A$(Max) level from the APTA guidelines at these mileages. For all of the SEPTA route mileage, the in-car $L_A$(Max) levels exceed APTA guidelines for the type of track being traversed.

## B.3 STATION NOISE

### B.3.1 $L_A$(Max) and $L_{eq}$ (Figures B-8, B-9)

Station average arrival-departure sound levels on the SEPTA system range from 80 to 98 dBA. Station sound levels may be delineated generally by station construction. The highest levels, in the 91 to 100 interval, are found in underground stations. Elevated stations are usually in the 86 to 90 dBA range, with slightly lower levels at the terminal station, Bridge-Pratt. The $L_A$(Max) at the at-grade station at Milbourne is only 80 dBA. Levels at the other at-grade stations, Fern Rock and 69th Street,

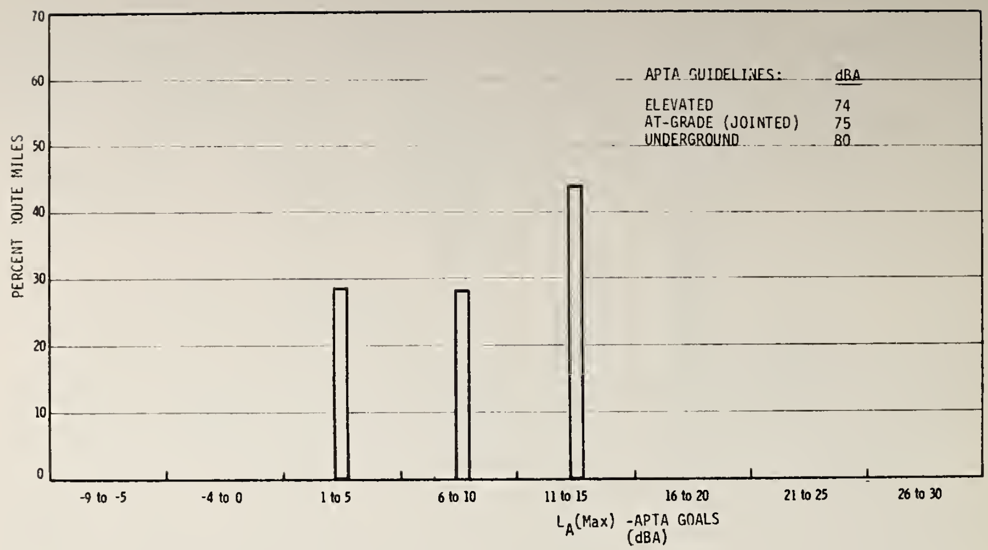



FIGURE B-7 SEPTA SYSTEM, IN-CAR NOISE GUIDELINE COMPARISON

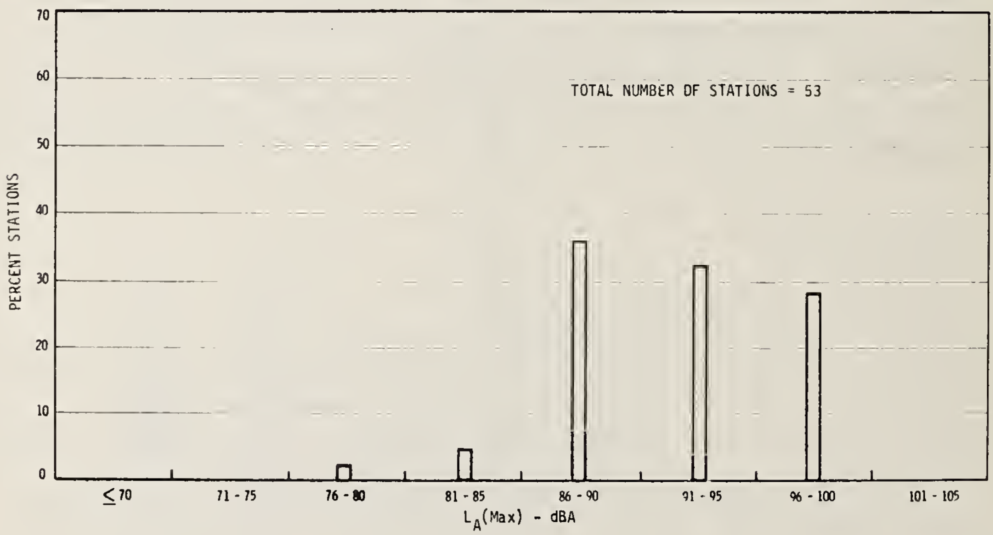



FIGURE B-8 SEPTA SYSTEM, IN-STATION MAXIMUM NOISE LEVELS

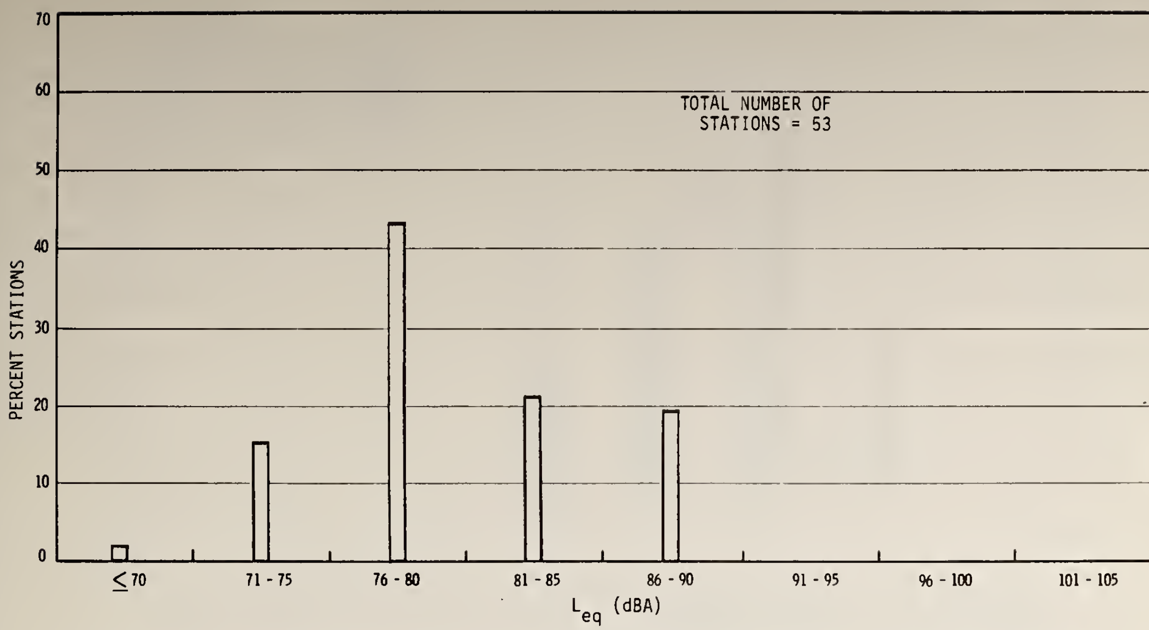



FIGURE B-9 SEPTA SYSTEM, IN-STATION EQUIVALENT SOUND LEVELS

were higher due to the wheel screech produced on the curves of near-by reversing loops (See Figure B-2).

The distribution of station $L_{eq}$ for the entire SEPTA system is concentrated in the 76 to 80 dBA range. The $L_{eq}$ values for SEPTA stations were measured by the contractor for a 30-minute sample of train pass-bys.

### B.3.2 In-Station Noise Exposure

The distribution of patronage versus station $L_{eq}$ levels for each line of the SEPTA system is shown in Figure B-10. Approximately 48 percent of all patrons experience noise of 81 dBA or greater. Patronage in elevated stations on the Market-Frankford Line dominates the low end of the distribution. Heavy patronage in the Market-Frankford underground stations is reflected in the spike at 81 to 85 dBA. The patronage of the Broad Street Line, however, is concentrated in the stations with lower noise levels, particularly in the 76 to 80 dBA range.

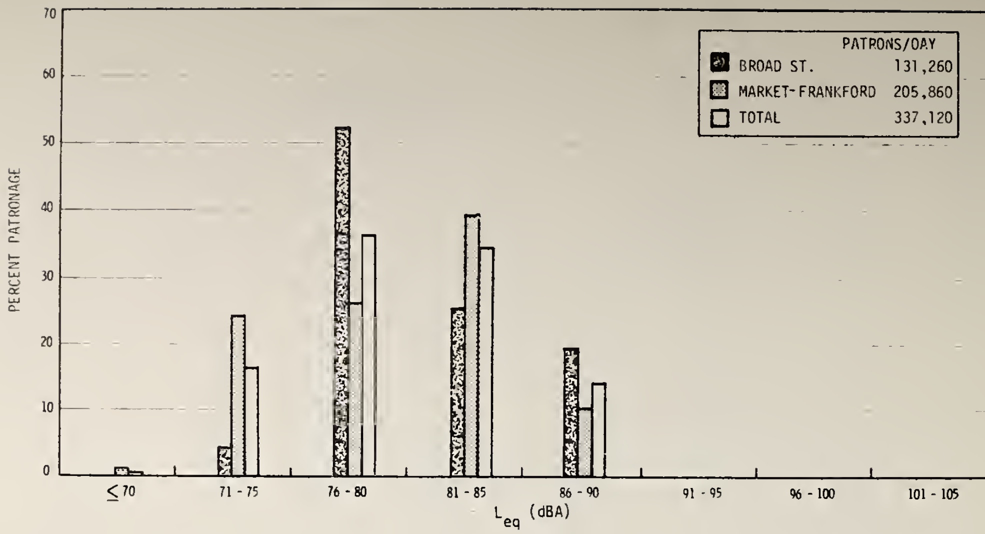



FIGURE B-10 SEPTA SYSTEM, IN-STATION NOISE EXPOSURE

### B.3.3 Comparison of SEPTA Station $L_A$(Max) with APTA Guidelines

As shown in Figure B-11, all SEPTA stations have $L_A$(Max) which exceed the APTA guidelines for that type of station, with the majority six to ten dBA above the guidelines.

## B.4 SEPTA WAYSIDE NOISE

### B.4.1 $L_A$(Max)

The A-weighted average maximum pass-by levels, $L_A$(Max), at 15 m (50 ft) from the near track center-line range from 76 to 89 dBA. The distributions of these values as a percentage of the residential and non-residential wayside mileages are shown in Figures B-12 and B-13, respectively. The highest noise levels, 89 dBA, occur along the steel elevated segments of the Market-Frankford Line, where cars operate at an average speed of 72 km/h (45 mph). A reduction in speed, to 25 km/h (20 mph), was shown to reduce the levels by two to three dBA along the elevated sections.

Lower noise levels occur along the at-grade track segments

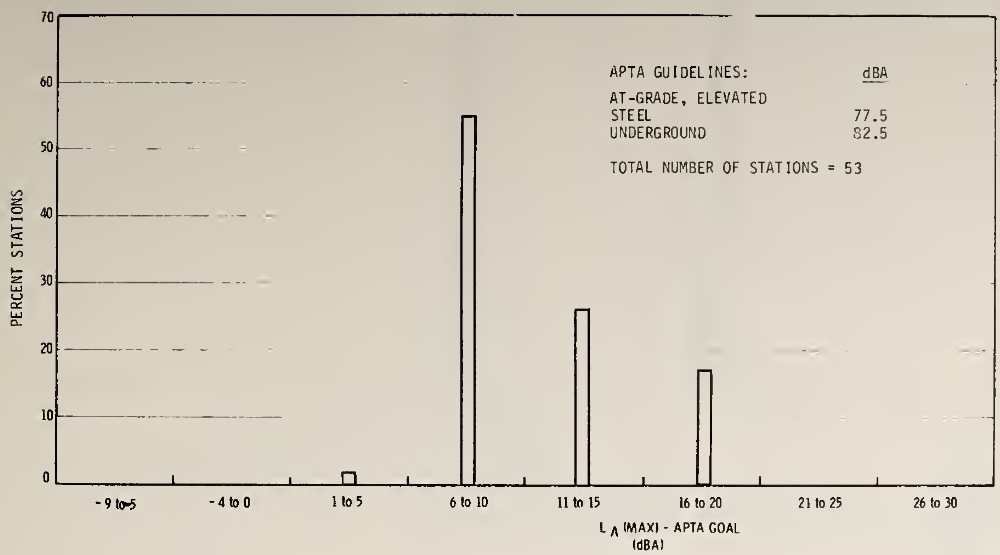



FIGURE B-11 SEPTA SYSTEM, IN-STATION NOISE GUIDELINE COMPARISON

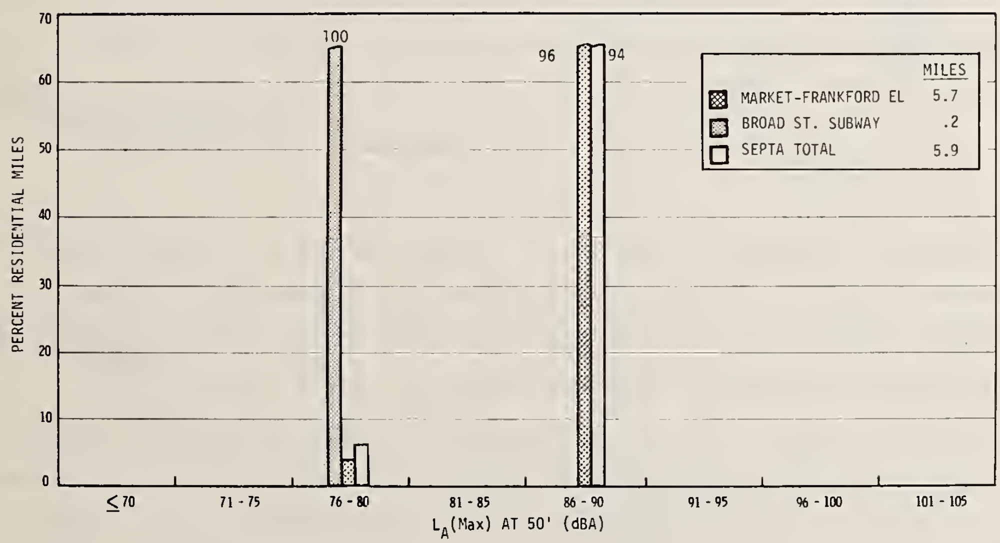



FIGURE B-12 SEPTA SYSTEM, DISTRIBUTION OF RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

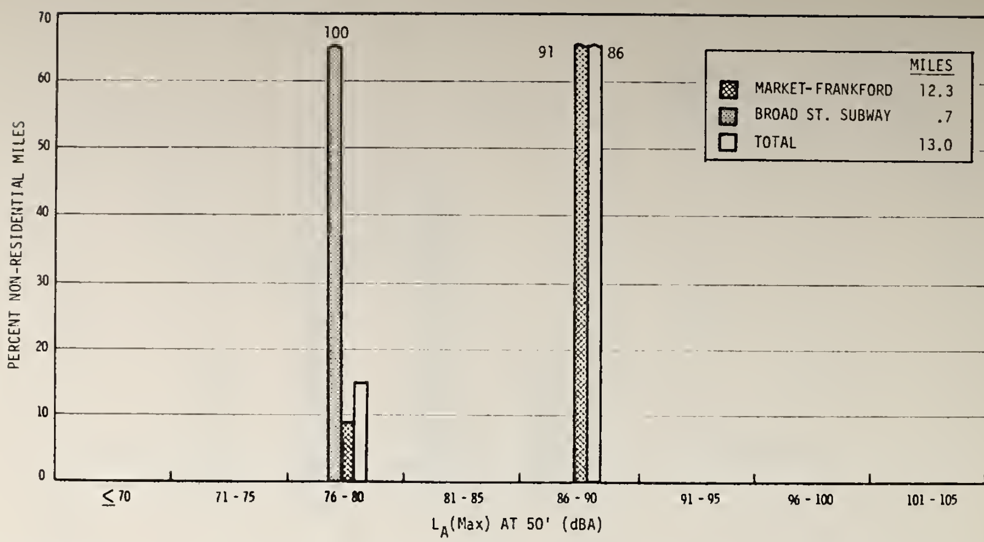



FIGURE B-13 SEPTA SYSTEM, DISTRIBUTION OF NON-RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

on both the Market-Frankford and Broad Street routes, with the $L_A$(Max) levels ranging from 76 to 78 dBA. The lowest levels were recorded adjacent to the Broad Street Line. Although the latter employs considerably older cars, the lower noise levels can be attributed to the difference in average operating speeds, 72 km/h (45 mph) for the Market-Frankford Line is opposed to 17 mph for the Broad Street Subway.

### B.4.2 $L_{dn}$(Trains)

Wayside equivalent day-night sound levels resulting only from train pass-bys, $L_{dn}$(Trains), are shown in Figure B-14. The $L_{dn}$(Trains) level is based on the pattern of wayside $L_A$(Max), and also reflects the number and duration of train pass-bys.

Both the high, 72 km/h (45 mph) and low, 32 km/h (20 mph)-speed elevated steel segments of the Market-Frankford Line produce an $L_{dn}$ (Trains) level of 74 dBA, even though there is a higher (3 dBA) $L_A$(Max) level adjacent ot the high-speed sections. This clearly shows the effect of train speed, and thereby the duration of the train pass-by, on the $L_{dn}$(Trains) level. The communities

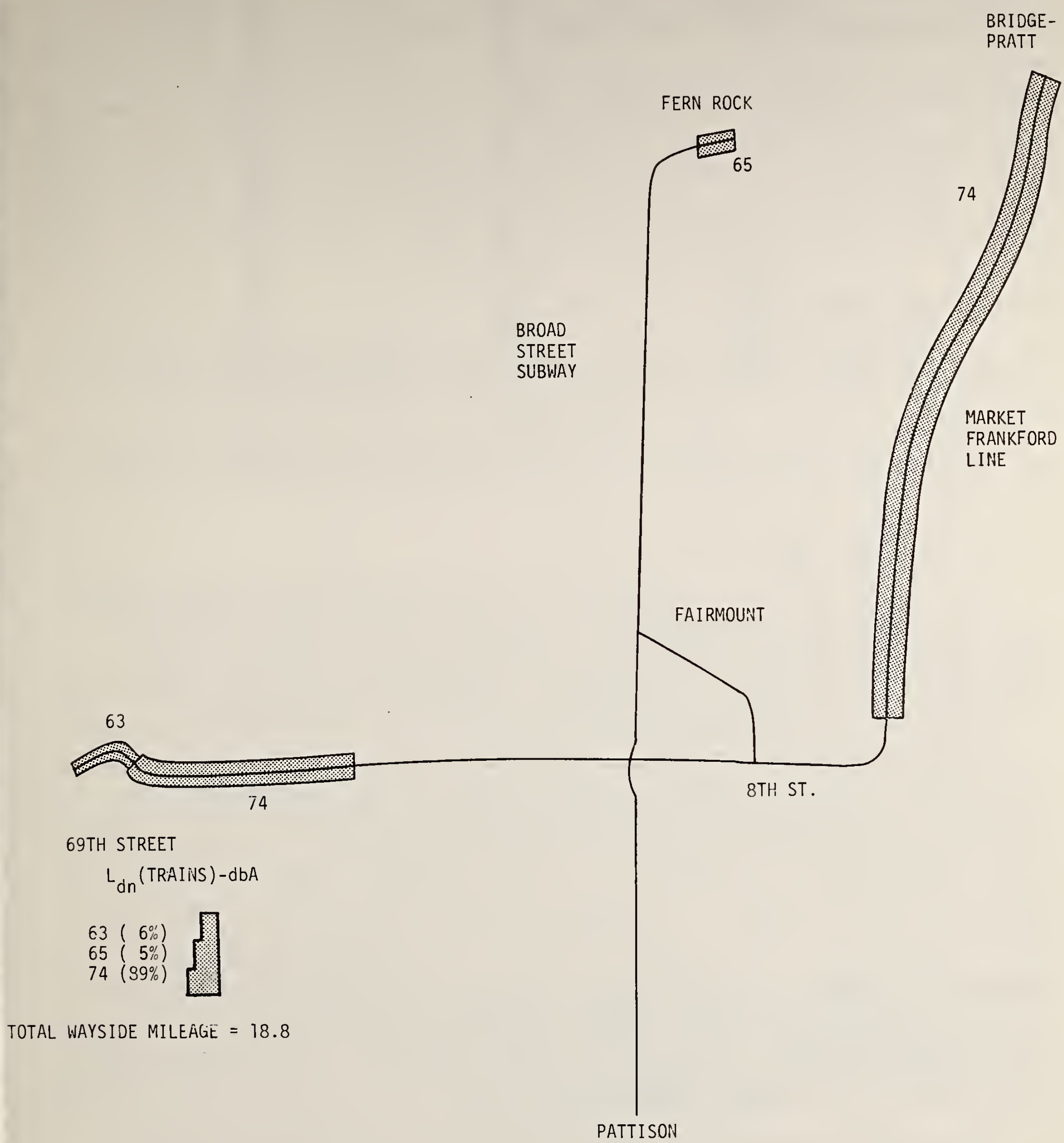



FIGURE B-14 SEPTA SYSTEM, WAYSIDE $L_{dn}$(TRAINS)

along the low-speed segment are subjected to a lower $L_A$(Max) level, but for a longer period of time.

A similar relationship develops when the two at-grade track sections are compared. The communities adjacent to the Broad Street route experience an $L_A$(Max) level two dBA lower than that found along the Market-Frankford route. However, due to the low operating speed, 27.4 km/h (17 mph) on the Broad Street Line, there is an $L_{dn}$(Trains) level of 65 dBA in these areas, which is two dBA higher than the level adjacent to the Market-Frankford route.

### B.4.3 $L_{dn}$(Ambient)

The average $L_{dn}$ (Ambient) levels for residential wayside communities resulting from all noise sources other than train pass-bys, are as follows: 66.6 for the Market-Frankford Line; 64.4 for the Broad Street Subway; and 66.5 for the total SEPTA system.

### B.4.4 Relative $L_{dn}$

The distribution of Relative $L_{dn}$, the difference between the $L_{dn}$ (from all noise sources) and $L_{dn}$(Ambient), shown in Figure B-15, reflects both the pattern of $L_{dn}$(Trains) shown in Figure B-14, and the $L_{dn}$(Ambient) distributions described above.

The Market-Frankford Line exhibits a wide range of Relative $L_{dn}$ levels, two to 25 dBA, and has a mean level of 7.8 dBA. A Relative $L_{dn}$ of two dBA is found in wayside communities adjacent to at-grade track (3 percent of route mileage), where a medium ambient level (64 dBA) is combined with a medium train level (63 dBA). Conversely, the highest Relative $L_{dn}$ (25 dBA) occurs in communities where the lowest $L_{dn}$(Ambient), 49 dBA, combines with a high $L_{dn}$(Trains) level, 74 dBA. Seventy-four percent of the residential mileage has a Relative $L_{dn}$ of seven dBA, an ambient level of 68 dBA, and a trains level of 74 dBA.

The Broad Street Line, which has only one section of above-ground at-grade track, has a Relative $L_{dn}$ of three dBA. The $L_{dn}$(Ambient) levels in the communities adjacent to this track are

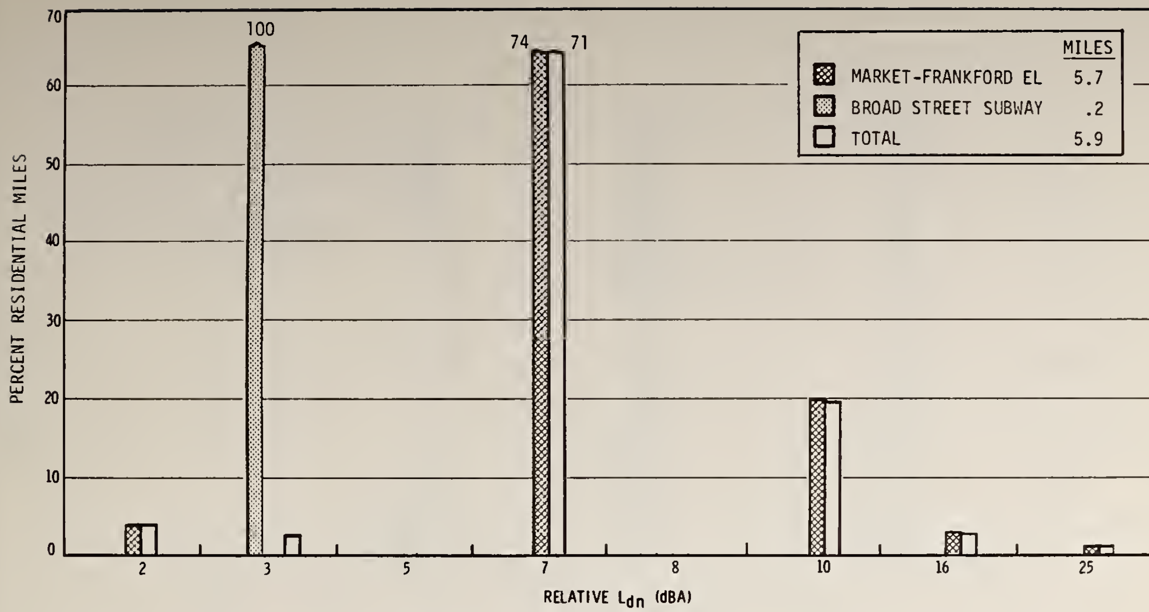



FIGURE B-15 SEPTA SYSTEM, DISTRIBUTION OF WAYSIDE RELATIVE $L_{dn}$

64 dBA with an $L_{dn}$(Trains) level of 65 dBA.

As more than 97 percent of the residential mileage of the SEPTA system wayside community is adjacent to track of the Market-Frankford Line, the Relative $L_{dn}$ distribution for the entire SEPTA system reflects that of the Market-Frankford Line. The range of Relative $L_{dn}$ levels is two to 25 dBA, with a mean level of 7.6 dBA. Seventy-one percent of the residential mileage experiences Relative $L_{dn}$ levels of seven dBA.

### B.4.5 <u>Wayside Exposure</u>

The total population residing within the 60-m (200-ft) corridor adjacent to the aboveground segments of SEPTA is estimated to be approximately 5470. Of this total nearly 92 percent resides in communities alongside the Market-Frankford Line.

Figure B-16 illustrates the distribution of the percent population against Relative $L_{dn}$. Approximately 86 percent of the total population is exposed to a Relative $L_{dn}$ level of seven dBA,

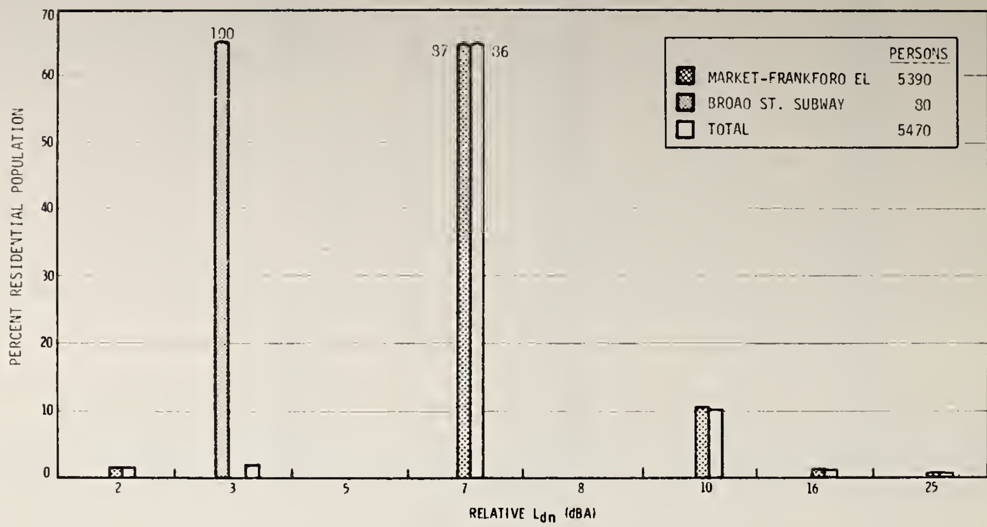



FIGURE B-16 SEPTA SYSTEM, WAYSIDE NOISE EXPOSURE

with nearly 11 percent exposed to levels of ten dBA or higher, and only three percent to Relative $L_{dn}$ levels of three dBA or lower.

### B.4.6 Comparison of SEPTA Wayside $L_A$(Max) with SEPTA Guidelines

The distribution of wayside **$L_A$(Max)** levels relative to the APTA guidelines for residential and non-residential areas abutting the rail right-of-way is shown in Figure B-17. All of the residential communities are subjected to $L_A$(Max) levels in excess of the APTA guidelines, with only four percent within ten dBA of the goals. Conversely, all of the non-residential areas are exposed to $L_A$(Max) levels within ten dBA of the APTA goals, with nearly 15 percent below the established guideline level.

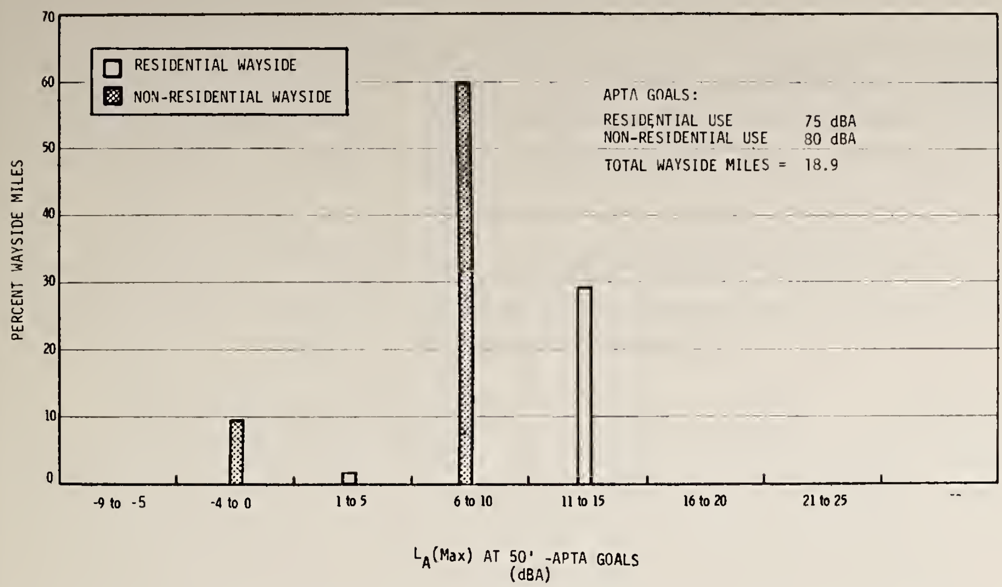



FIGURE B-17 SEPTA SYSTEM, WAYSIDE NOISE GUIDELINE COMPARISON

# APPENDIX C - URBAN RAIL NOISE ASSESSMENT OF PATCO SYSTEMS

## C.1 SYSTEM DESCRIPTION (See Table C-1)

The Delaware River Port Authority operates the Port Authority Transit Corporation (PATCO) high-speed line between Philadelphia and Lindenwold, New Jersey (See Figure C-1).

The route is 22.7 km (14.2 mi) long, with 59 percent at-grade or on elevated embankment, 17 percent underground, 11 percent on the Benjamin Franklin Bridge and approaches, 7 percent in an open-cut and 6 percent on concrete viaduct.

Continuously welded rail is used, except in the subway between the 8th and Race Street Station and the 16th Street Station in Philadelphia, and on the bridge and its approaches, where the rail is jointed. In the latter sections, the roadbed consists of short wood ties set in concrete. The aboveground sections east of Broadway Station have a roadbed of ballast and wood ties, except for the two concrete viaduct sections, where the rail is fastened directly onto the concrete structure.

### C.1.1 Stations

All 12 stations are of the center platform type. The six New Jersey stations have been acoustically treated with thin metal-perforated ceilings backed with a layer of fiberglass insulation. Since the time of the noise measurements, a thirteenth station (Franklin Square) has been added, underground between City Hall and the 8th and Market Street Stations.

### C.1.2 Transit Vehicles

PATCO uses 75 Budd Company electric cars. Twenty-five of these are single-unit, double-end cars seating 72, and the remaining 50 cars are arranged as 25 married pairs, each car seating 80.

The cars entered into service when the system began operations in 1969. The car interiors are fully climate controlled, with

TABLE C-1 PATCO SYSTEM SUMMARY (1 OF 2)

| | |
|---|---|
| A. ROUTE PHYSICAL | |
| 1. Length | 14.2 Miles |
| 2. Track Type | Jointed Rail, Wood Ties in Concrete; Welded Rail, Ballast & Ties, Wood Ties in Concrete |
| 3. Track Structure Mileage | |
| a. Underground | 2.5 Miles |
| b. Elevated Embankment | 8.3 Miles |
| c. Concrete Viaduct | .9 Miles |
| d. Bridge | 1.5 Miles |
| e. In-Cut | 1.0 Miles |
| 4. Number of Stations | 13 |
| B. VEHICLES | |
| 1. Year Manufactured | 1969/1969 |
| 2. Number in Service | 25 Single Cars/50 arranged in 25 Married pairs |
| 3. Acoustical Treatment | Thermal/acoustical insultation on walls, ceiling and underside of the car |
| C. SYSTEM SCHEDULING | |
| 1. Running Time | 23 Minutes |
| 2. Average Speed | 40 mph (including stops) |

TABLE C-1 PATCO SYSTEM SUMMARY (2 OF 2)

| | | | |
|---|---|---|---|
| D. POPULATION DATA | | | |
| 1. Daily Ridership | 39,500 persons | | |
| 2. Wayside Population Density (Mean) | 6400/sq. mi. | | |
| 3. Wayside Population within 200 ft. | 2080 persons | | |
| 4. Residential Land Use (Length-% of Total Wayside) | 9.3 Miles (39.7%) | | |
| E. IN-CAR SOUND LEVELS | Single Car | Double Car | Systemwide |
| 1. Average Inter-station $L_A$(Max) | 75.7 dBA | 75.9 dBA | 75.8 dBA |
| 2. $L_A$(Max) Standard Dev. | 3.64 | 2.88 | 3.20 |
| 3. $L_{eq}$(R) | 72.3 dBA | 72.7 dBA | 72.5 dBA |
| F. IN-STATION SOUND LEVELS | | | |
| 1. Average Station $L_A$(Max) | 80.3 dBA | | |
| 1.5 Range of $L_A$(Max) | 70-89 dBA | | |
| 2. Average Station $L_{eq}$ | 72.5 dBA | | |
| G. WAYSIDE COMMUNITY SOUND LEVELS | | | |
| 1. Average $L_A$(Max) Range @ 50' | 83.8 dBA | | |
| 1.5 $L_A$(Max) Range @ 50' | 76-94 dBA | | |
| 2. Average $L_{dn}$(Trains) | 63.3 dBA | | |
| 3. Average $L_{dn}$(Ambient) | 59.0 dBA | | |
| 4. Average Relative $L_{dn}$ | 6.3 dBA | | |


FIGURE C-1 PATCO RAIL TRANSIT LINE

thermal/acoustical insulation on the underside of the car covered with stainless steel sheets. The walls and ceiling also contain acoustical/thermal insulation to increase the car-body transmission loss. In addition, the upholstered seat covers provide some measure of acoustical absorption.

### C.1.3 Route Description

The PATCO Line travels underground, 2.4 km (1.5 mi) from the terminus, 16th Street in Philadelphia, to the Delaware River. It crosses the river on the Benjamin Franklin Bridge, 2.4 km (1.5 mi), and returns underground 1.6 km (1.0 mi) through Camden. East of the Broadway Station the line is aboveground, primarily on elevated embankment track, 13.3 km (8.3 mi) (See Figure C-2).

Wheel squeal is evident both at the Lindenwold yard loop, and at several underground locations in both Philadelphia and Camden. Impact noise occurs at insulated track joints. The line runs parallel to the Pennsylvania-Reading Seashore Line east of the Haddonfield Station to the Lindenwold terminus.

Running time over the route is 23 minutes, with a maximum speed of 64 km/h (40 mph) in the subway sections and 120 km/h (75 mph) on aboveground track. Since the compilation of the noise measurements, aboveground operating speeds have been restricted 96 km/h (60 mph).

Current (1977) operating headways range from five minutes at peak periods to 60 minutes from 1 A.M. to 5 A.M., with train lengths varying from one to six cars. Headways during most of the day are 7.5 minutes.

## C.2 IN-CAR NOISE

### C.2.1 $L_A$(Max)

The lowest in-car noise plateau levels (72 dBA) occur when the route operates on elevated embankment track or over the Benjamin Franklin Bridge. Conversely, underground sections have the highest $L_A$(Max) levels, five to ten dBA higher than the above in-car level.

# LEGEND FOR FIGURE C-2

TRACK STRUCTURE

- ES = ELEVATED STEEL
- EE = ELEVATED EMBANKMENT
- UG = UNDERGROUND
- CV = CONCRETE VIADUCT
- IC = IN CUT
- AG = AT GRADE
- MS = MEDIAN STRIP
- EC = ELEVATED CONCRETE
- A = AERIAL

$X_{AB}$ = INTERSTATION DISTANCE (MILES)

$N_A/N_B$ = STATION NOISE AT STATION A/B (dBA)

$N_i$ = IN-CAR NOISE (dBA)

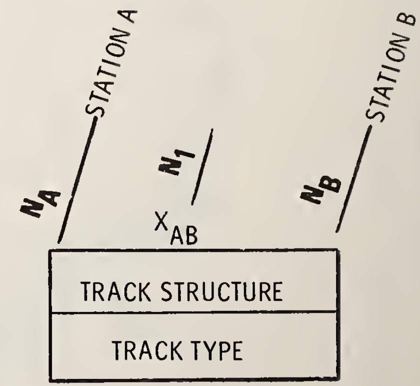
$N_{50}$ = WAYSIDE NOISE AT 50 FEET (dBA)

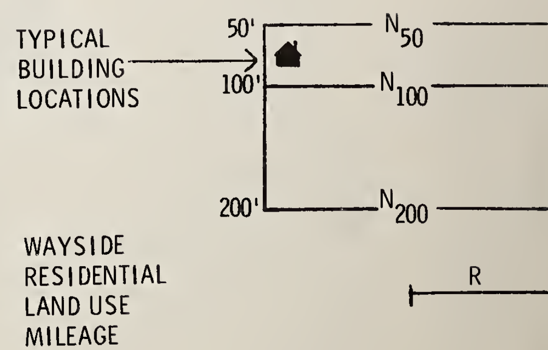
$N_{100}$ = WAYSIDE NOISE AT 100 FEET (dBA)

$N_{200}$ = WAYSIDE NOISE AT 200 FEET (dBA)

R = WAYSIDE RESIDENTIAL LAND USE MILEAGE (BOTH SIDES OF TRACK)

DATA UNIQUE TO PARTICULAR SYSTEMS ARE NOTED ON SYSTEM SCHEMATICS



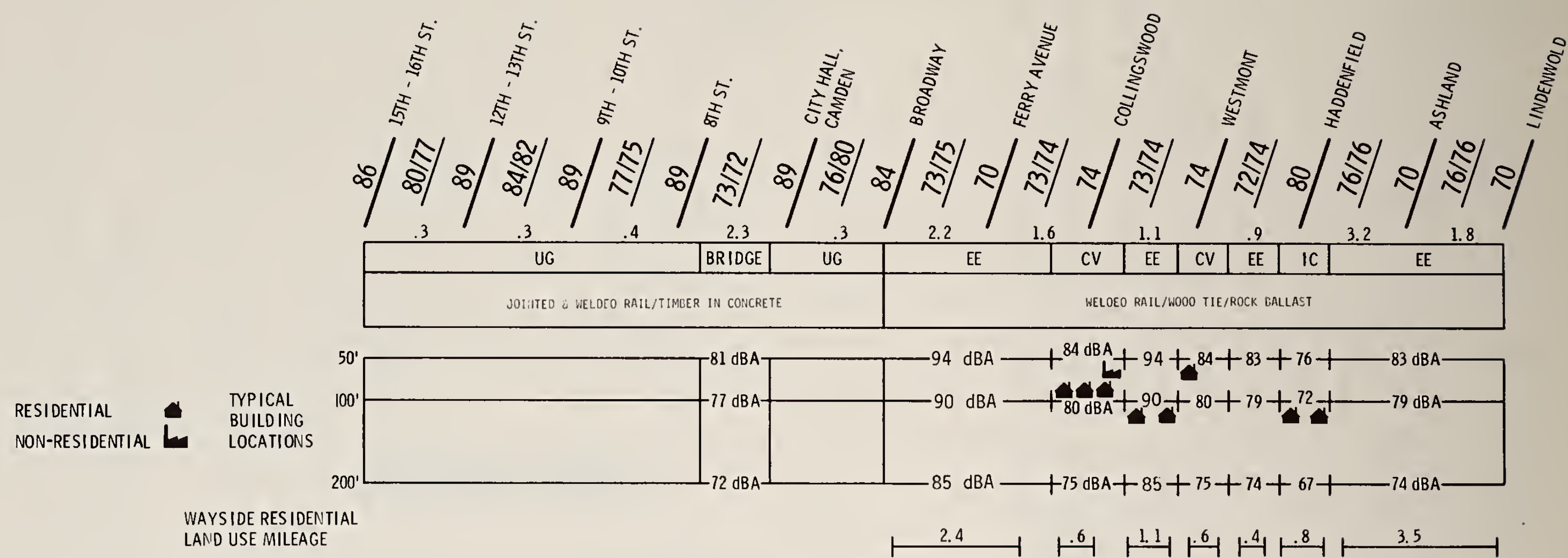



FIGURE C-2 THE LINDENWOLD LINE

Figure C-3 represents the distribution of route miles at various $L_A$(Max) levels for both the single and double cars operating on the Lindenwold Line. Nearly all the mileage can be categorized by levels ranging from 71 to 80 dBA, with 58 percent between 71 and 75 dBA. Note that only a slight fluctuation in levels is recorded due to the difference in car configurations.

The more detailed information depicted in Figure C-2 shows the actual in-car $L_A$(Max) measurements. From the figure it can be seen that the elevated embankment track east of Haddonfield Station has higher in-car $L_A$(Max) levels. One probable explanation for this is that the greater inter-station distances allow for a higher operating speed, thus generating higher in-car noise plateaus.

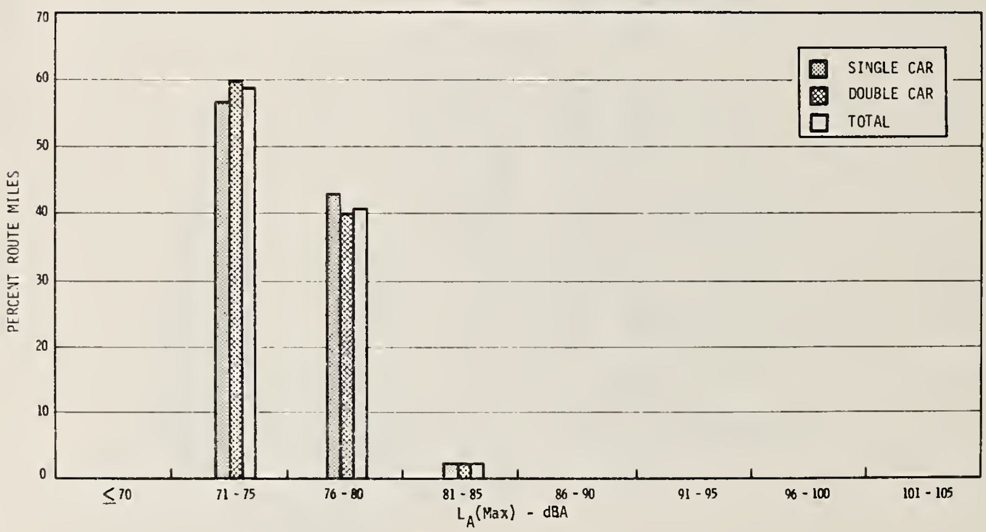



FIGURE C-3 PATCO SYSTEM, DISTRIBUTION OF IN-CAR PLATEAU NOISE LEVELS

### C.2.2 In-Car Equivalent Noise Levels

The route equivalent noise level, $L_{eq}$ (R), which characterizes the in-car environment on the PATCO system, is 72.5 dBA.

The distribution of route miles by inter-station $L_{eq}$ is shown in Figure C-4. Approximately 96 percent of the mileage is exposed to $L_{eq}$ levels of 75 dBA or less, with 85 percent between 71 and 75 dBA.

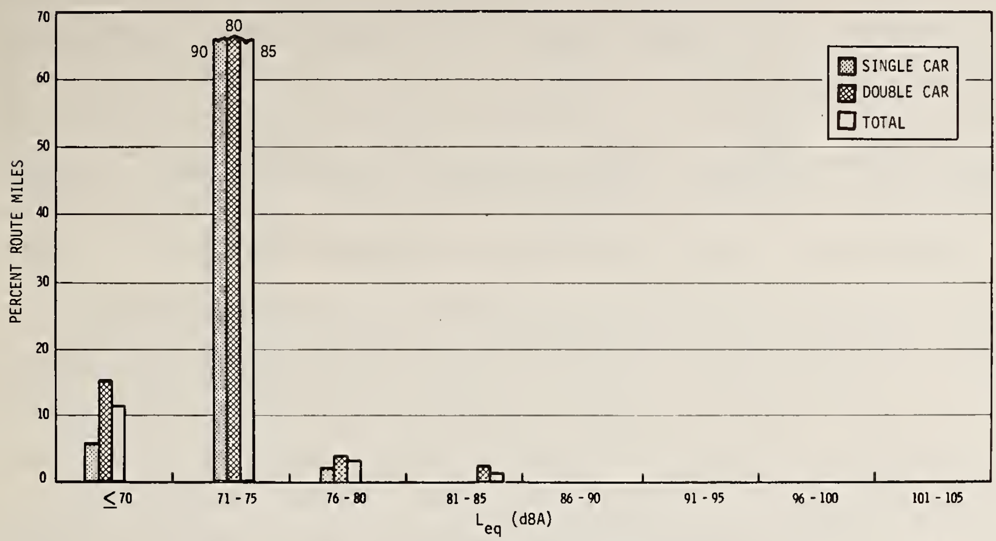



FIGURE C-4 PATCO SYSTEM, DISTRIBUTION OF IN-CAR EQUIVALENT SOUND LEVELS

### C.2.3 In-Car Exposure

Figure C-5 represents an estimate of in-car exposure. Using the methods and assumptions discussed in Appendix H, one can distribute a measure of ridership (people-hours) over in-car inter-station $L_{eq}$ levels. When trip time information (not available for this analysis) is supplied, the average trip time and the total number of patrons exposed at each $L_{eq}$ level can be specified. Nearly 96 percent of the people-hours are less than or equal to 75 dBA, with approximately 85 percent between 71 and 75 dBA.

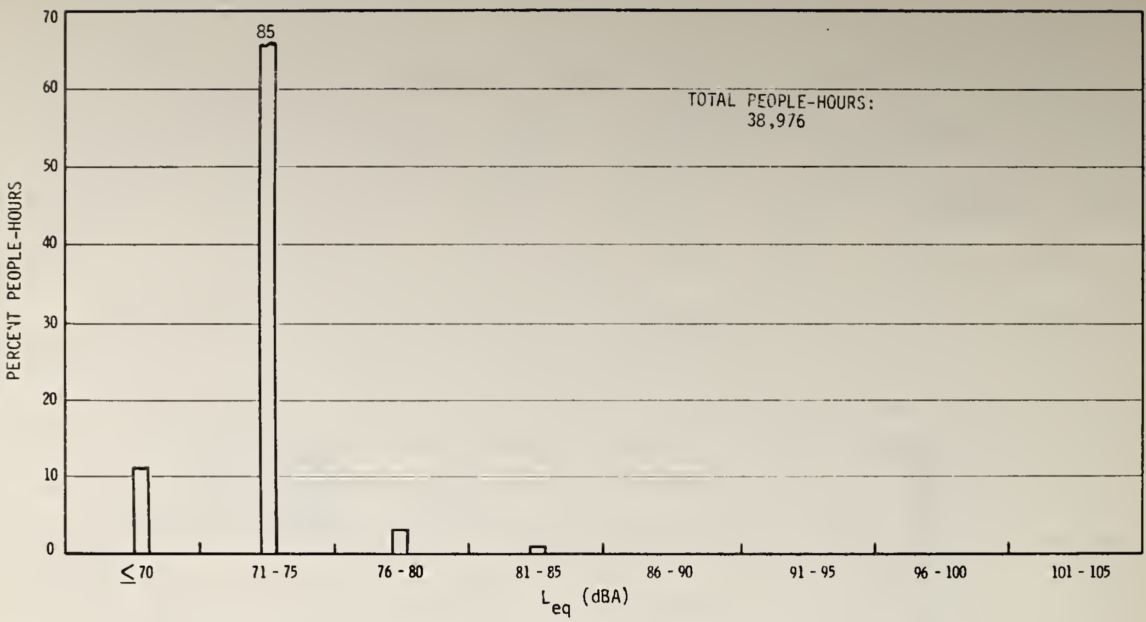



FIGURE C-5 PATCO SYSTEM, IN-CAR NOISE EXPOSURE

### C.2.4 Comparison of PATCO In-Car $L_A$(Max) with APTA Guidelines

Figure C-6 illustrates the distribution of route-miles versus the measured in-car $L_A$(Max) values relative to the APTA goals. All of the mileage is within ten dBA of the established guidelines, with 23 percent below the APTA goals. The elevated embankment track east of the Haddonfield Station accounts for all the mileage in the six to ten dBA range.

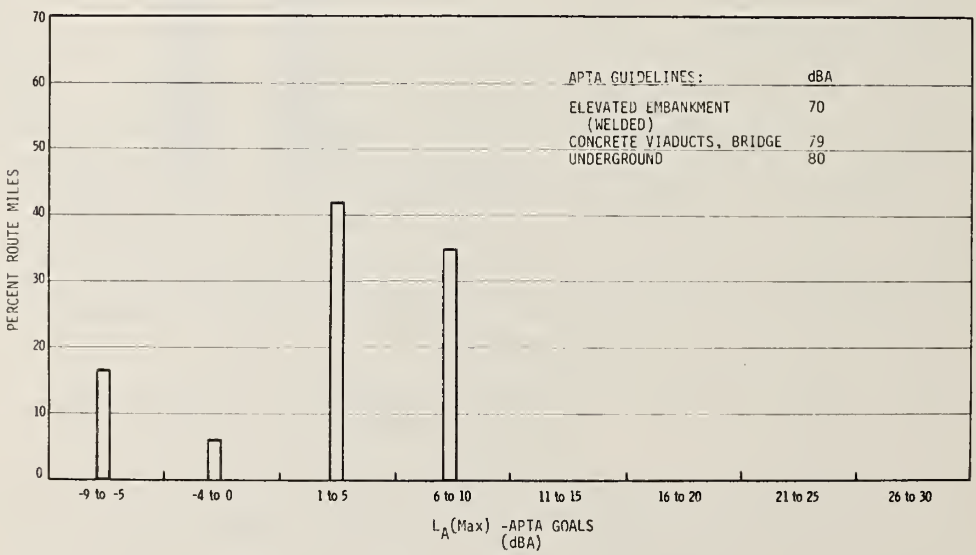



FIGURE C-6 PATCO SYSTEM, IN-CAR NOISE GUIDELINE COMPARISON

## C.3 STATION NOISE

### C.3.1 $L_A$(Max) and $L_{eq}$

The average station arrival and departure sound levels on the Lindenwold Line range from 70 to 89 dBA. The major determinant of the sound levels is station construction. The lowest $L_A$(Max) levels (70 dBA) are recorded at elevated embankment stations. Haddonfield, the only station in an open cut, has the highest level for aboveground stations (80 dBA). Subway stations show $L_A$(Max) levels between 84 and 89 dBA, with two-thirds of the stations at the higher level. Figure C-7 illustrates the preceding pattern by distributing the percent stations over $L_A$(Max) ranges. From lowest to highest $L_A$(Max), the peaks correspond to elevated embankment, concrete viaduct, open-cut, and subway stations.

The distribution of station $L_{eq}$ values is shown in Figure C-8; they range from 64 to 81 dBA. All aboveground stations have $L_{eq}$ levels of 70 dBA or less.

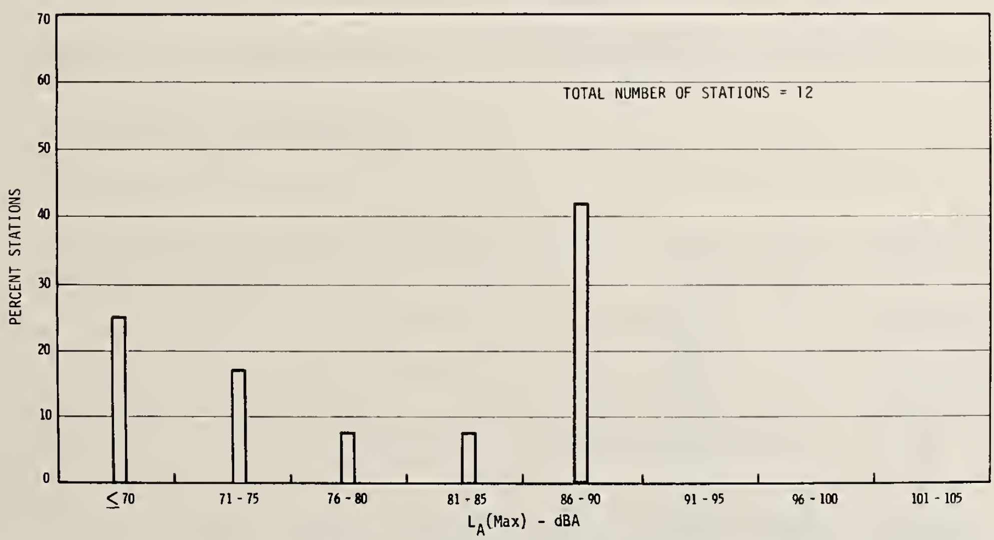



FIGURE C-7 PATCO SYSTEM, IN-STATION MAXIMUM NOISE LEVELS

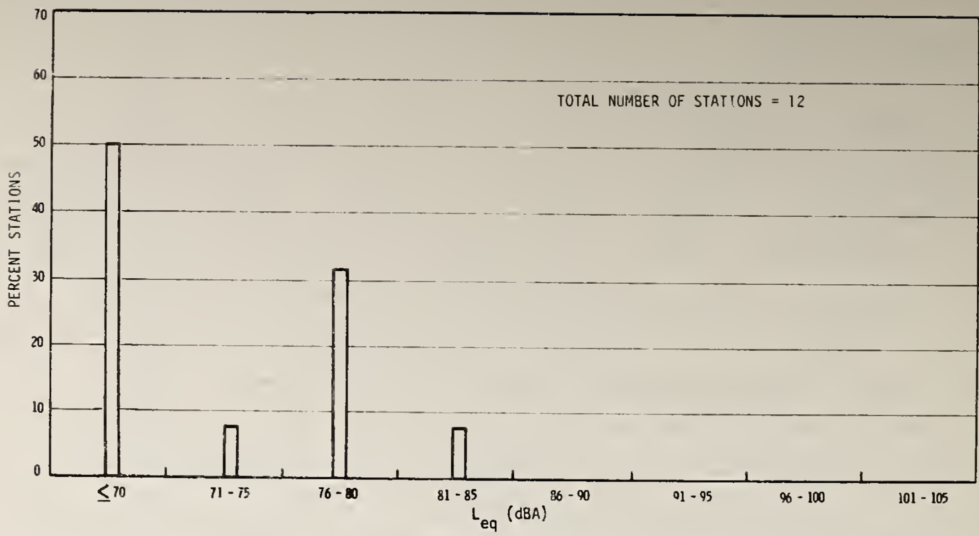



FIGURE C-8 PATCO SYSTEM, IN-STATION EQUIVALENT SOUND LEVELS

## C.3.2 In-Station Noise Exposure

Figure C-9 shows a distribution of patronage versus station $L_{eq}$ levels. Approximately 48 percent of the PATCO passengers waiting on platforms (for an average of 3.5 minutes) experience $L_{eq}$ levels less than or equal to 70 dBA. This is as expected, as 50 percent of the stations show $L_{eq}$ levels of 70 dBA or less.

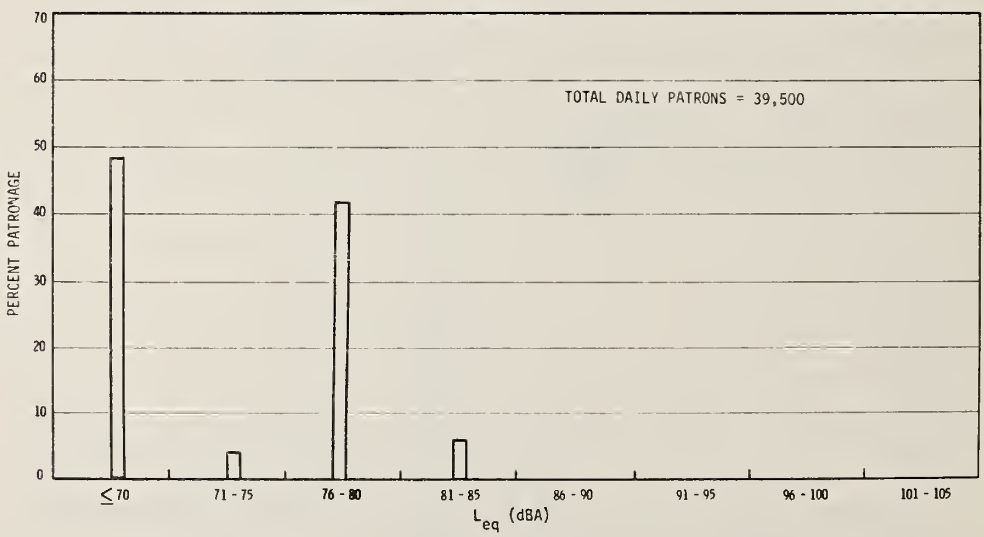



FIGURE C-9 PATCO SYSTEM, IN-STATION NOISE EXPOSURE

### C.3.3 Comparison of PATCO Station $L_A$(Max) with APTA Guidelines

As shown in Figure C-10, half of the stations on the Lindenwold Line are below the APTA guidelines and half are above. All the aboveground stations have $L_A$(Max) levels lower than the APTA goals, with the elevated embankment stations more than seven dBA lower. Conversely, the subway stations are above the APTA levels; two-thirds of them are between six and ten dBA greater.

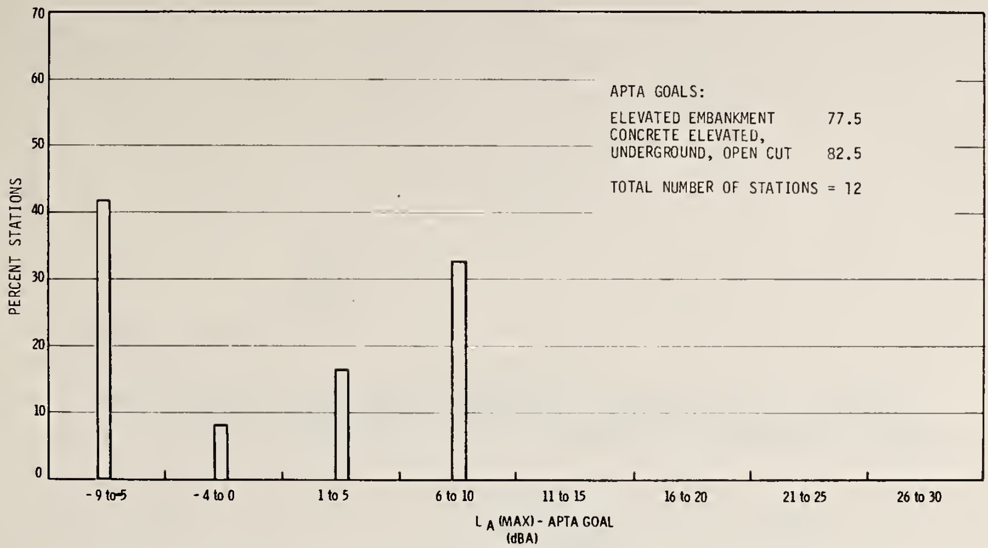



FIGURE C-10 PATCO SYSTEM, IN-STATION NOISE GUIDELINE COMPARISON

## C.4 PATCO WAYSIDE NOISE

### C.4.1 $L_A$(Max)

The average A-weighted maximum pass-by levels, $L_A$(Max), at 15 m (50 ft) from the near track center-line range from 76 to 94 dBA. Figures C-11 and C-12 show the distribution of these values as a percentage of residential and non-residential wayside mileages, respectively. The highest noise levels, 83 and 94 dBA, occur alongside elevated embankment and concrete viaduct track, respectively.

Lower noise levels are observed adjacent to track which is operating in an open cut, and along the Benjamin Franklin Bridge wayside. These levels, 76 and 81 dBA, respectively, are affected

by several parameters. The lower levels recorded abutting the open-cut track are primarily due to the difference in track construction, whereas the lower levels adjacent to the bridge are due mainly to the difference in normal operating speeds, 64 km/h (40 mph) on the bridge against 120 km/h (75 mph) on the other, aboveground track sections.

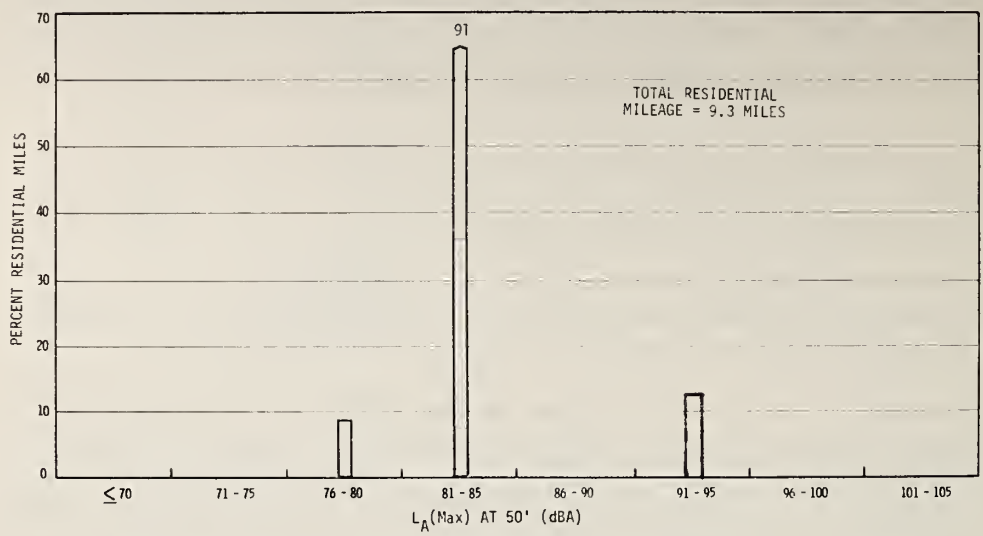



FIGURE C-11 PATCO SYSTEM, DISTRIBUTION OF RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

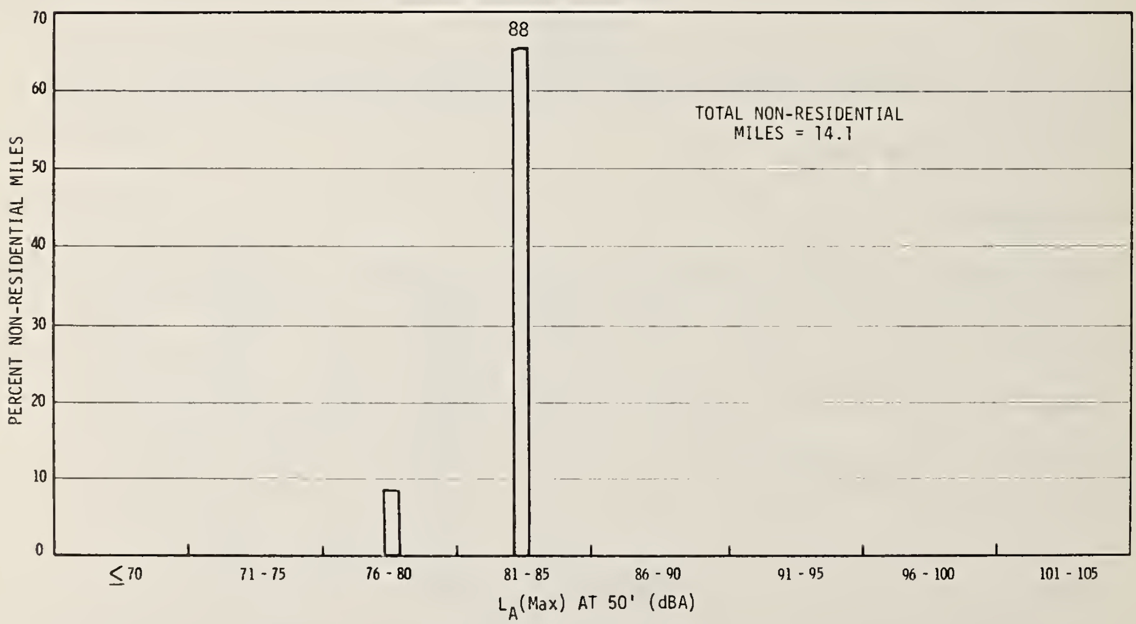



FIGURE C-12 PATCO SYSTEM, DISTRIBUTION OF NON-RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

### C.4.2 $L_{dn}$ (Trains)

Wayside equivalent day-night sound levels resulting only from train pass-bys, $L_{dn}$ (Trains), are shown in Figure C-13. The distribution of $L_{dn}$ (Trains) is based on the pattern of wayside $L_A$(Max) levels. As expected, the lowest level, 56 dBA, is recorded alongside open-cut track. $L_{dn}$ (Trains) levels of 63 and 74 dBA are observed adjacent to elevated embankment and concrete viaduct track, respectively.

An $L_{dn}$(Trains) level of 64 dBA was recorded alongside the Benjamin Franklin Bridge wayside. Although the wayside $L_A$(Max) is three dBA lower for this section, the lower operating speed, 64 km/h (40 mph) is opposed to 120 km/h (75 mph), raises the $L_{dn}$(Trains) level two to three dBA. The net effect is that the same level is observed adjacent to the high-speed concrete viaduct track and the bridge.

### C.4.3 $L_{dn}$ (Ambient)

The average $L_{dn}$ (Ambient) level resulting from all noise sources other than train pass-by noise which is used to characterize the noise environment for wayside communities, is 59.0 dBA for the total PATCO system. $L_{dn}$ (Ambient) levels range from 49 to 64 dBA.

### C.4.4 Relative $L_{dn}$

The distribution of Relative $L_{dn}$ in the PATCO wayside is shown in Figure C-14, and reflects both the pattern of $L_{dn}$(Trains) (Figure C-13) and the $L_{dn}$(Ambient) levels discussed above.

PATCO's Relative $L_{dn}$ levels range from one to 14 dBA, with an average level of 5.3 dBA. The highest level, 14 dBA, is recorded in communities where the lowest $L_{dn}$(Ambient), 49 dBA, is combined with a medium $L_{dn}$(Trains) level, 63 dBA. The majority of the residential mileage, 48 percent, experiences Relative $L_{dn}$ levels of four to six dBA. In these communities, $L_{dn}$(Ambient) levels of 58 or 61 dBA combine with $L_{dn}$(Trains) levels of 63 or 64 dBA. The lowest Relative $L_{dn}$ levels (one to two dBA), affecting

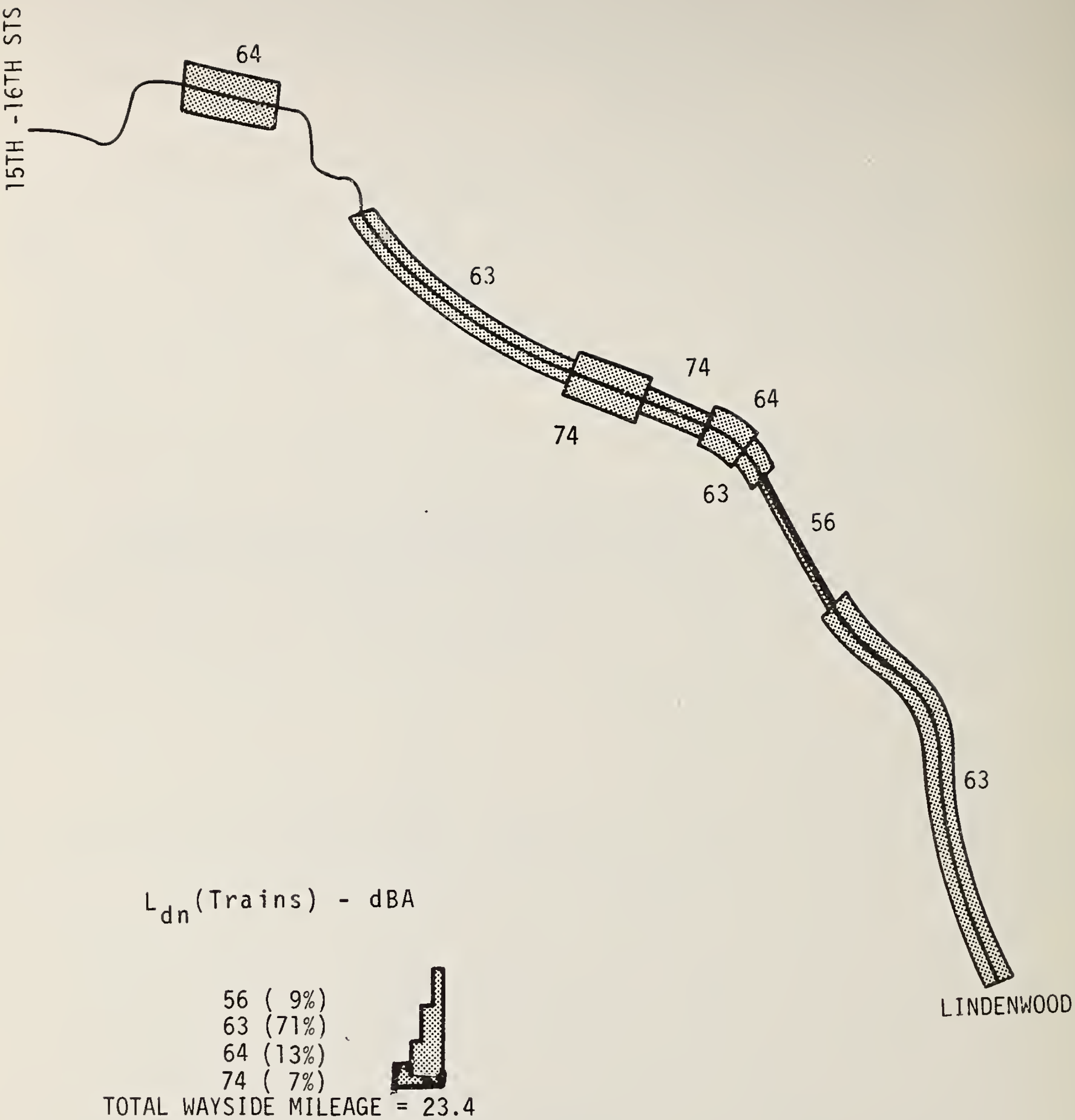



FIGURE C-13 PATCO WAYSIDE $L_{dn}$ (TRAINS)

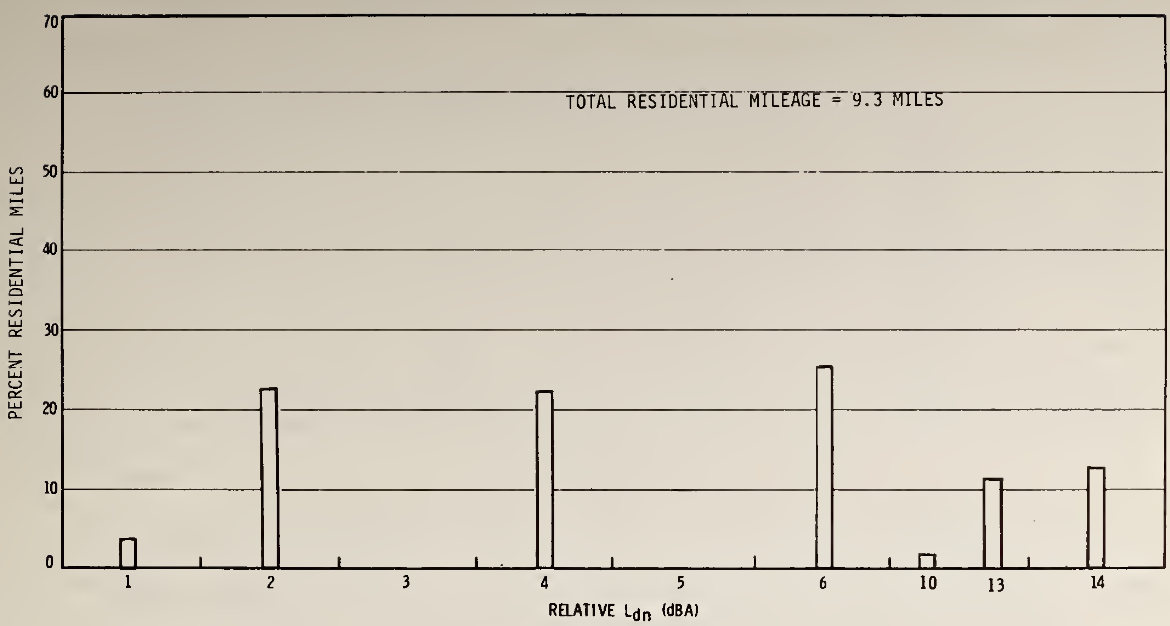



FIGURE C-14 PATCO SYSTEM, DISTRIBUTION OF WAYSIDE RELATIVE $L_{dn}$

28 percent of the residential areas, are found in communities where the ambient levels are greater than or equal to the trains levels.

### C.4.5 Wayside Exposure

The total population residing within the 60-m (200-ft) corridor adjacent to the aboveground segments of PATCO is estimated to be approximately 1965, 81 percent of whom reside alongside elevated embankment track.

Figure C-15 illustrates the distribution of the percent total population within the corridor against Relative $L_{dn}$. Less than one percent of the total population is exposed to a level of 14 dBA, while more than 48 percent experiences Relative $L_{dn}$ levels of one to three dBA.

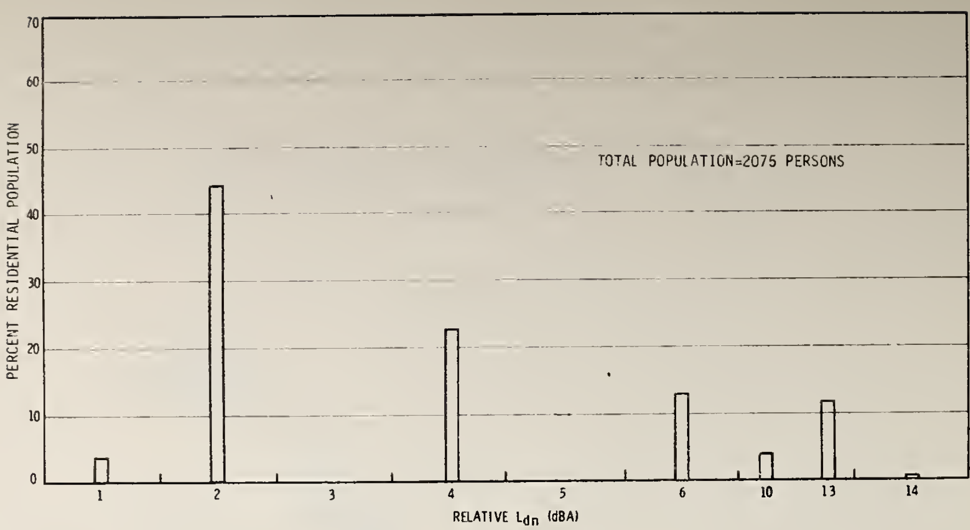



FIGURE C-15 PATCO SYSTEM, WAYSIDE NOISE EXPOSURE

## C.4.6 Comparison of PATCO Wayside $L_A$(Max) with APTA GUIDELINES

The distribution of wayside $L_A$(Max) levels relative to the APTA goals for residential and non-residential areas adjacent to the rail right-of-way is shown in Figure C-16. All of the residential communities' $L_A$(Max) levels are within 20 dBA of the APTA guidelines, with levels in nine percent of the areas within 15 dBA of the guidelines. The $L_A$(Max) levels recorded in non-residential wayside communities are all within five dBA of the APTA goals, with approximately 9 percent below the established levels.

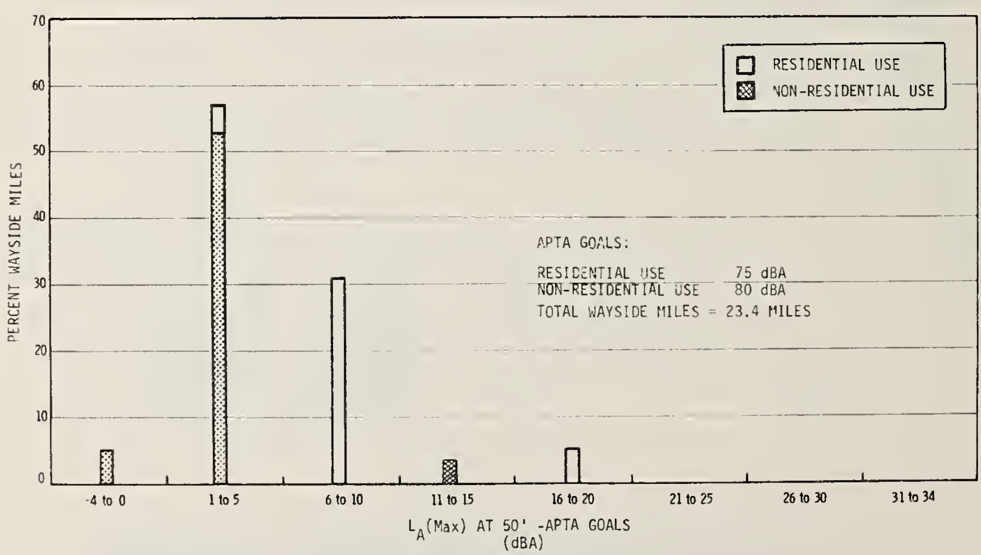



FIGURE C-16 PATCO SYSTEM, WAYSIDE NOISE GUIDELINE COMPARISON

# APPENDIX D - URBAN RAIL NOISE ASSESSMENT OF RTA SYSTEMS

## D.1 SYSTEM DESCRIPTION (See Table D-1)

The Greater Cleveland Regional Transit Authority (RTA), formerly the Cleveland Transit System (CTS), operates the rapid transit route (Airport Line) which serves Hopkins International Airport, the downtown central business district, and East Cleveland (See Figure D-1). The route is approximately 19 miles in length with the following type of track: 5 percent underground, 45 percent at-grade, 46 percent open-cut and four percent elevated embankment.

The roadbed of this route consists of wood tie on ballast, with field-welded rail. The track gauge is 1.43 m (4 feet 8 1/4 in.), 6.4 mm (1/4 in.) tighter than standard railroad gauge However, the wheel gauge is set for standard track gauge.

### D.1.1 Stations

The RTA Airport Line consists of 18 stations, the majority of which are situated on either open-cut or at-grade structures (there are seven of each type). The most prevalent type of station platform configuration is the center platform.

Some center platform stations have vertical divisions which shield patrons from train noise radiating directly from the other side. The underground terminal at Public Square Station has corrugated and perforated steel facing covering some of the side pillars and beams.

### D.1.2 Transit Vehicles

The transit fleet consists of approximately 110 rail vehicles. The oldest cars, built in 1955 and 1958 by the St. Louis Car Company, are of two varieties: single cars and double units. The double units are 29.6 m (95.5 ft) in length and comprise 65 percent of the fleet; the single cars are 14.7 m (48.5 ft) long and make up 16 percent of the fleet. The St. Louis cars seat 54

TABLE D-1 RTA SYSTEM SUMMARY (1 OF 2)

| | |
|---|---|
| A. ROUTE PHYSICAL | |
| 1. Length | 19.0 Miles |
| 2. Track Type | Welded Rail, Ballast & Wood Ties |
| 3. Track Structure Mileage | |
| a. Underground | 1.0 Miles |
| b. Elevated Embankment | .7 Miles |
| c. At-Grade | 8.5 Miles |
| d. In-Cut | 8.8 Miles |
| 4. Number of Stations | 18 |
| B. VEHICLES | St. Louis Cars/Pullman Cars |
| 1. Year Manufactured | 1955, 1958/1967 |
| 2. Number in Service | 68, 20/ 20 |
| 3. Acoustical Treatment | No / No |
| C. SYSTEM SCHEDULING | |
| 1. Running Time | 36 Minutes |
| 2. Average Running Speed | 53 mph (without stops) |
| D. POPULATION DATA | |
| 1. Daily Ridership | 37,114/day |
| 2. Wayside Population Density (Mean) | 14,470/sq. mi. |
| 3. Wayside Population within 200 ft. | 2,825 persons |

TABLE D-1 RTA SYSTEM SUMMARY (2 OF 2)

| | | |
|---|---|---|
| D. POPULATION DATA (Cont.) | | |
| 4. Residential Land Use (Length-% of Total Wayside) | 6.5 miles (18%) | |
| E. IN-CAR SOUND LEVELS | St. Louis Cars/Pullman Cars | RTA Total |
| 1. Average Inter-station $L_A$(Max) | 83.7 dBA/83.9 dBA | 83.8 dBA |
| 2. $L_A$(Max) Standard Dev. | 1.22 dBA/ .99 dBA | 1.46 dBA |
| 3. $L_{eq}$(R) | 81.5 dBA/81.7 dBA | 81.6 dBA |
| F. IN-STATION SOUND LEVELS | | |
| 1. Average Station $L_A$(Max) | 82.3 dBA | |
| 1.5 Range of $L_A$(Max) | 77-88 dBA | |
| 2. Average Station $L_{eq}$ | 73.4 dBA | |
| G. WAYSIDE COMMUNITY SOUND LEVELS | | |
| 1. Average $L_A$(Max) @ 50' | 95.1 dBA | |
| 1.5 Range of $L_A$(Max) 50' | 84-99 dBA | |
| 2. Average $L_{dn}$(Trains) | 75.0 dBA | |
| 3. Average $L_{dn}$(Ambient) | 63.3 dBA | |
| 4. Average Relative $L_{dn}$ | 11.9 dBA | |

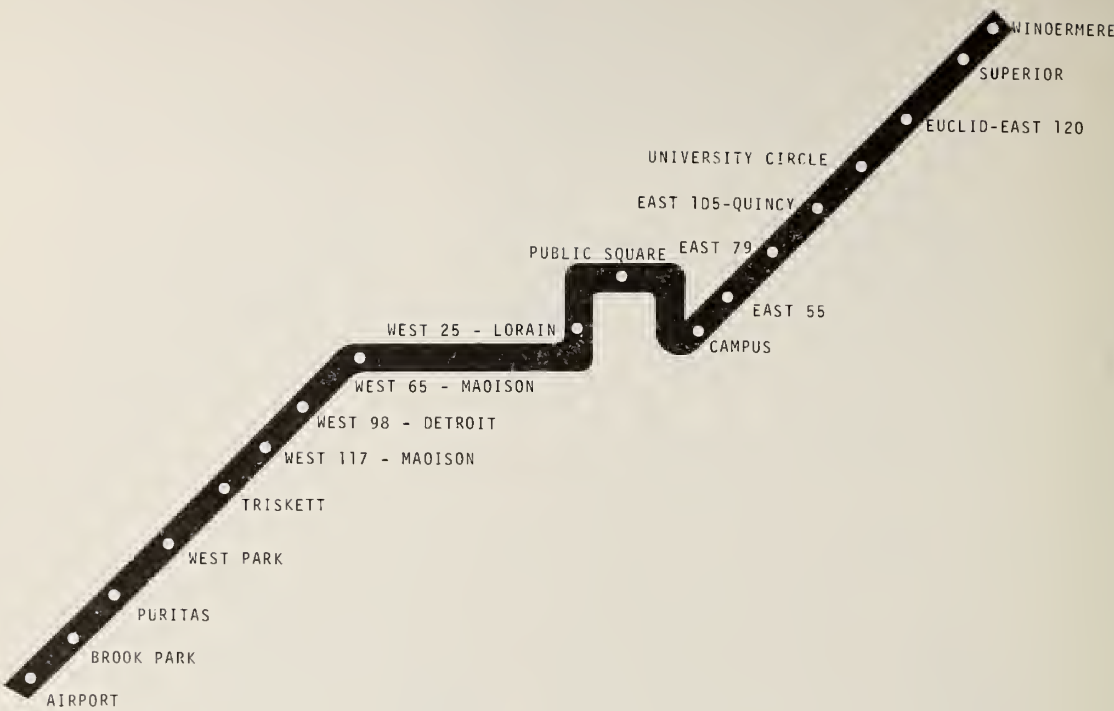



FIGURE D-1 RTA RAIL TRANSIT LINES

passengers in the single car unit and 55 in each of the double car units. Neither model contains acoustical absorption in the car interior, and both are used almost exclusively during the peak hours. The newer vehicles, built by Pullman Standard in 1967, are single units, 21.3 m (70 ft) in length, and operate at all times. These vehicles are constructed of stainless steel with fiberglass ends, and air conditioned. Seating capacity for the Pullman Standard cars is 80 passengers.

During the compilation of the noise data, three Pullman cars were equipped with carpeting on the floors and sidewall kick panels. This produced a slight reduction in the in-car noise level, as noted below.

### D.1.3 Route Description

The Airport Line is underground at its Airport terminus. It proceeds through the subway tunnel, 0.8 km (0.5 mi), onto at-grade track, 10.2 km (6.4 mi), into an open cut, 6.4 km (4.0 mi), to the second underground section at Public Square, 0.8 km (0.5 mi). From here it travels in an open cut, 7.7 km (4.8 mi), onto another at-grade section, 3.4 km (2.1 mi). The final link to the terminus at Windemere is on an elevated embankment, 1.1 km (0.7 mi) (See Figure D-2).

The RTA route parallels both the Penn Central tracks on the western portion of the line, and the Norfolk and Western right-of-way on the southern end of the line.

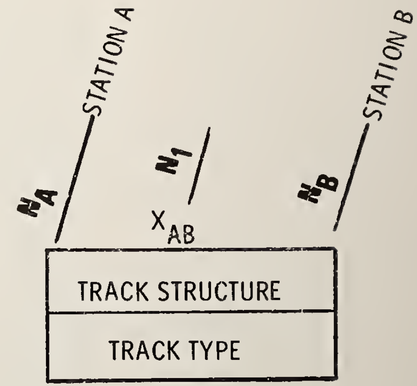
Short radius curves, which produce wheel squeal, are located at the Windermere yard approach tracks, and at the entrance and exit to the Public Square Station. Intermittent moderate squeal noise or flange "sing" can be heard on most curves and on tangent track, possibly produced by the tight gauge.

Trains currently operate between 4:00 A.M. and midnight from Windermere to Airport, with additional trains operating between Brookpark and Public Square during the peak hours. Early morning operation, called Owl Service, was terminated in May of 1977, after the noise measurements were completed.

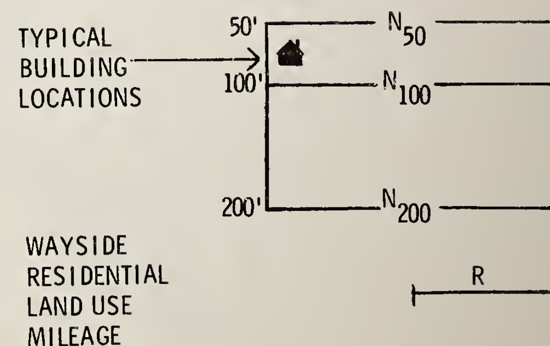
# LEGEND FOR FIGURE D-2

TRACK STRUCTURE

| | | |
|---|---|---|
| ES | = | ELEVATED STEEL |
| EE | = | ELEVATED EMBANKMENT |
| UG | = | UNDERGROUND |
| CV | = | CONCRETE VIADUCT |
| IC | = | IN CUT |
| AG | = | AT GRADE |
| MS | = | MEDIAN STRIP |
| EC | = | ELEVATED CONCRETE |
| A | = | AERIAL |




| | | |
|---|---|---|
| $X_{AB}$ | = | INTERSTATION DISTANCE (MILES) |
| $N_A/N_B$ | = | STATION NOISE AT STATION A/B (dBA) |
| $N_i$ | = | IN-CAR NOISE (dBA) |
| $N_{50}$ | = | WAYSIDE NOISE AT 50 FEET (dBA) |
| $N_{100}$ | = | WAYSIDE NOISE AT 100 FEET (dBA) |
| $N_{200}$ | = | WAYSIDE NOISE AT 200 FEET (dBA) |
| R | = | WAYSIDE RESIDENTIAL LAND USE MILEAGE (BOTH SIDES OF TRACK) |




DATA UNIQUE TO PARTICULAR SYSTEMS ARE NOTED ON SYSTEM SCHEMATICS

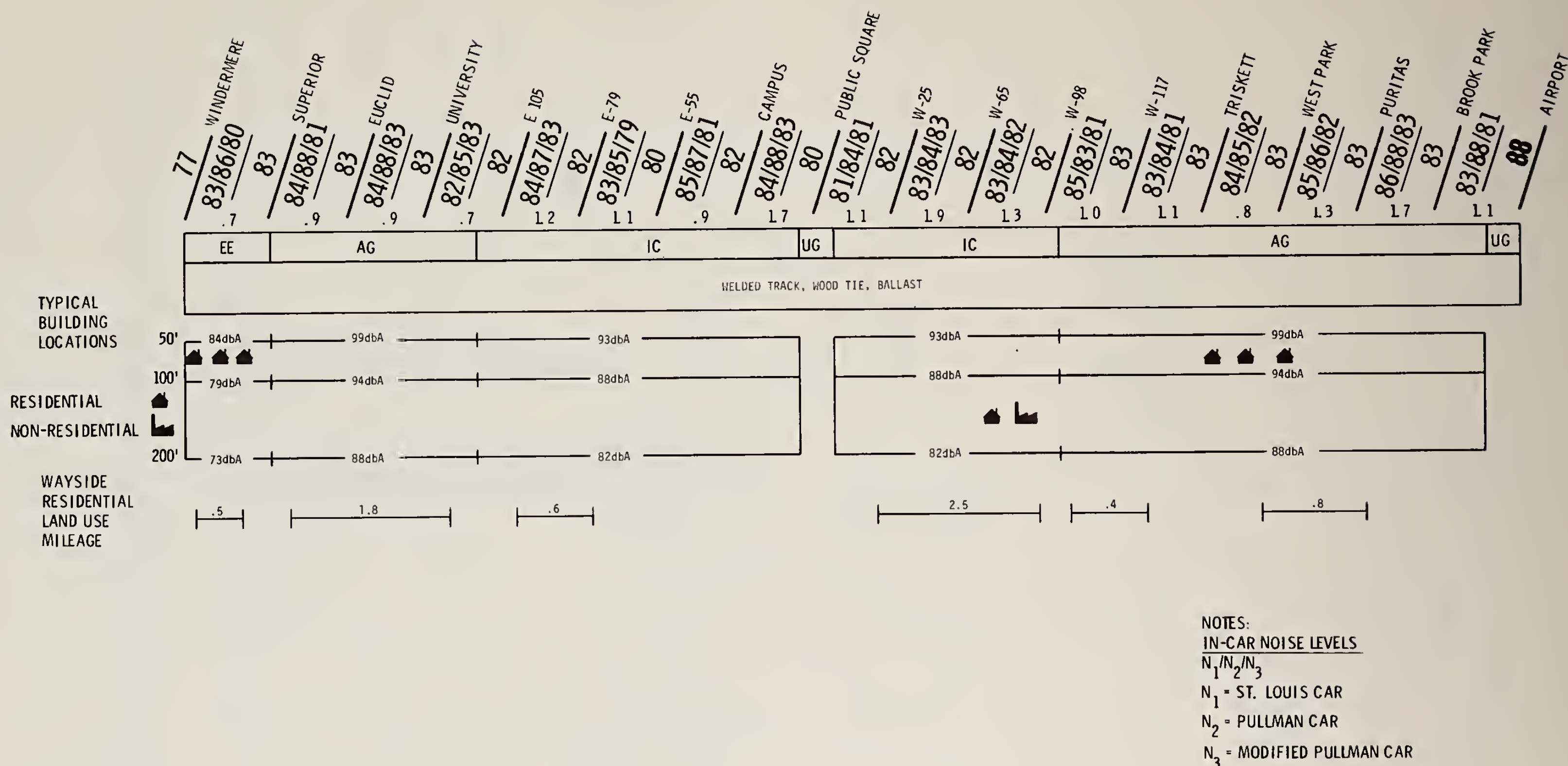



FIGURE D-2 RTA SYSTEM, AIRPORT LINE

Running time between Windermere and Airport is 36 minutes. Average train operating speeds are 88 km/h (55 mph) for the Pullman Standard cars and 75 km/h (47 mph) for the St. Louis cars. Train headways range from four minutes during rush hours to 15 minutes at off-peak hours. Train lengths range from one single car to three double cars for the rush hour.

## D.2 IN-CAR NOISE

### D.2.1 $L_A$(Max)

In-car $L_A$(Max) levels in all car types on the RTA are concentrated in the 81 to 90 dBA range (see Figure D-3). For 54 percent of the route, in-car noise levels in the Pullman cars are in the 86 to 90 dBA range. Pullman cars modified with carpeting and fabric-covered seats have in-car $L_A$(Max) of 76 to 80 dBA for nine percent of the route; they never exceed 83 dBA (see Figure D-2). There is no consistent relationship between in-car $L_A$(Max) and track structure for any of the car types, as shown in Table D-2.

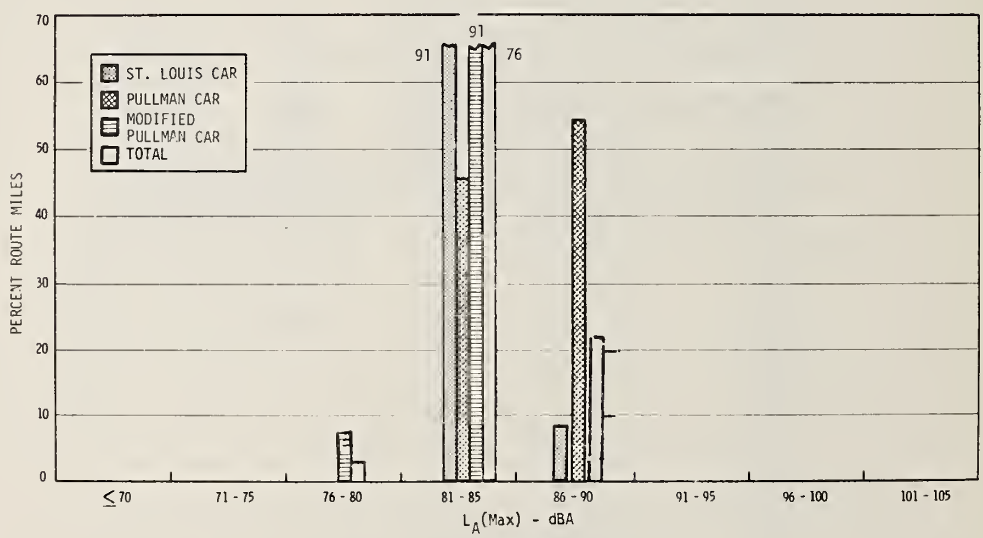



FIGURE D-3 RTA SYSTEM, DISTRIBUTION OF IN-CAR PLATEAU NOISE LEVELS

### D.2.2 In-Car Equivalent Noise Levels

The route equivalent level, $L_{eq}(R)$, characterizing the in-car noise environment for a complete end-to-end trip is 81.6 dBA. The disbribution of route miles by interstation $L_{eq}$ is shown in Figure D-4. The distribution is concentrated in the 81 to 85 range. Of particular interest is the breakdown by car type. In-car environments in the St. Louis cars have an $L_{eq}$ of 81 to 85 dBA for most of the route. Average sound levels in the modified Pullman cars are in the 76 to 80 range for 58 percent of the route. Unmodified Pullman cars have the highest levels, with 33 percent of the route mileage in the 86 to 90 dBA interval.

### D.2.3 In-Car Exposure

Figure D-5 represents an estimate of in-car exposure for the RTA. Using methods and assumptions discussed in Appendix H, one obtains a measure of ridership by weighting patronage by estimated trip times. The result, expressed in people-hours, was distributed over the inter-station in-car $L_{eq}$ levels. The distribution is concentrated in the 81 to 85 dBA interval. Given accurate trip time information for the system (not available for this analysis), one could use this distribution to specify the average time exposed to these $L_{eq}$ levels and the total number of patrons exposed at each level.

### D.2.4 Comparison of RTA In-Car $L_A$(Max) with APTA Guidelines

As shown in Figure D-6, in-car $L_A$(Max) levels exceed the APTA guidelines for the entire route. The welded at-grade and embankment track exceed the guidelines by 11 dBA or more, with most of the in-cut sections exceeding APTA goals by only five to ten dBA. This is explained by the lower goals for welded-rail track. As mentioned previously, the most significant determinants of the in-car noise levels on the RTA are the narrow track gauge, and the relatively high speed of the vehicles.

TABLE D-2 RTA IN-CAR NOISE SUMMARY

| | AT-GRADE (Welded) | IN-CUT | EMBANKMENT |
|---|---|---|---|
| St. Louis Cars | 84 dBA | 83 dBA | 83 dBA |
| Pullman Cars | 86 dBA | 86 dBA | 86 dBA |
| Modified Pullman Cars | 82 dBA | 82 dBA | 80 dBA |

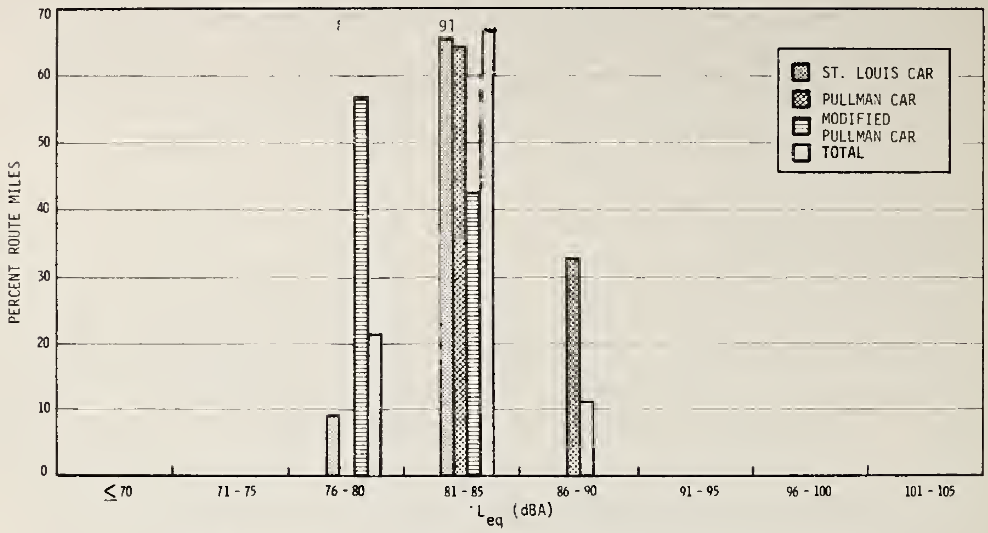



FIGURE D-4 RTA SYSTEM, DISTRIBUTION OF IN-CAR EQUIVALENT SOUND LEVELS

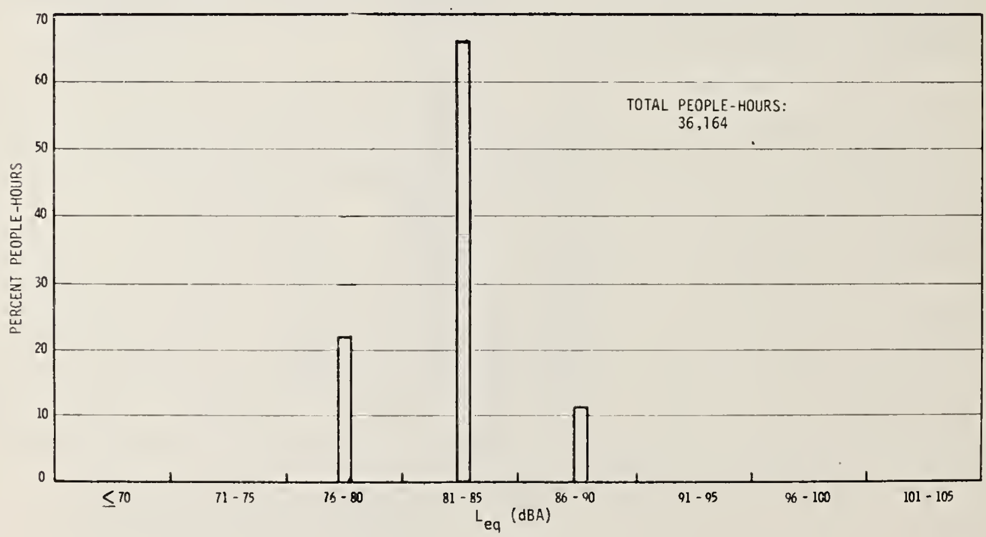



FIGURE D-5 RTA SYSTEM, IN-CAR NOISE EXPOSURE

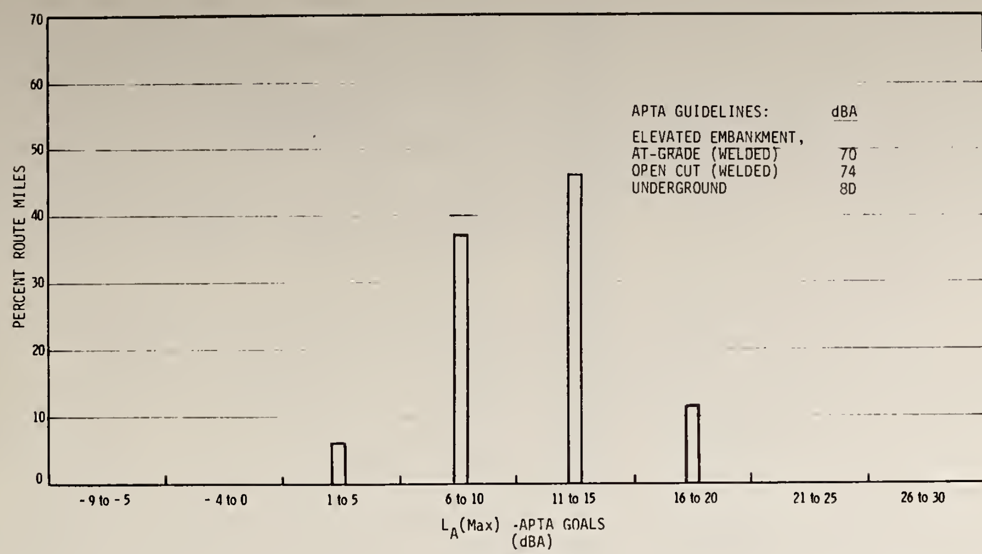



FIGURE D-6 RTA SYSTEM, IN-CAR NOISE GUIDELINE COMPARISON

## D.3 STATION NOISE

### D.3.1 $L_A$(Max) and $L_{eq}$ (See Figures D-7, D-8)

Station average arrival-departure sound levels on the RTA range from 77 to 88 dBA. All but two of the stations have an $L_A$(Max) in the 80 to 85 dBA range. The lower measured noise levels at the Windermere Station may be attributed to the placement of the microphone, which was located so as to be at the center of multi-car trains, rather than the one-car trains predominantly operated. The higher noise levels at the Airport Station are to be expected, as this station is underground. Public Square is also an underground station, but speeds of approaching trains are generally low.

The $L_{eq}$ values given for RTA stations were measured or derived from a 30-minute sample of train pass-bys. The only station not in the 71 to 75 dBA range is Airport Station.

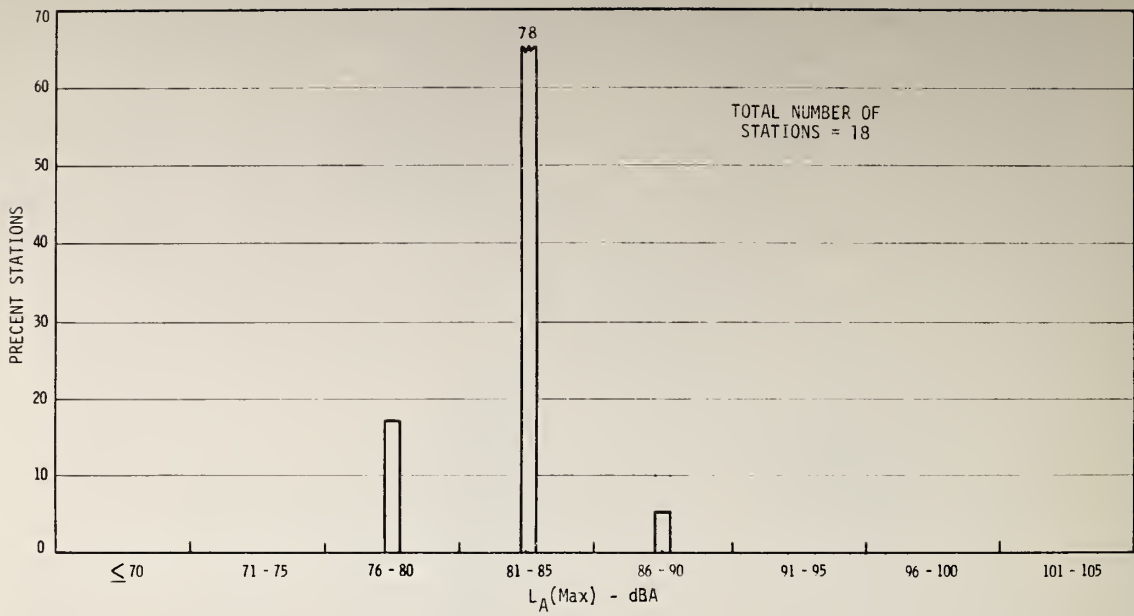



FIGURE D-7 RTA SYSTEM, IN-STATION MAXIMUM NOISE LEVELS

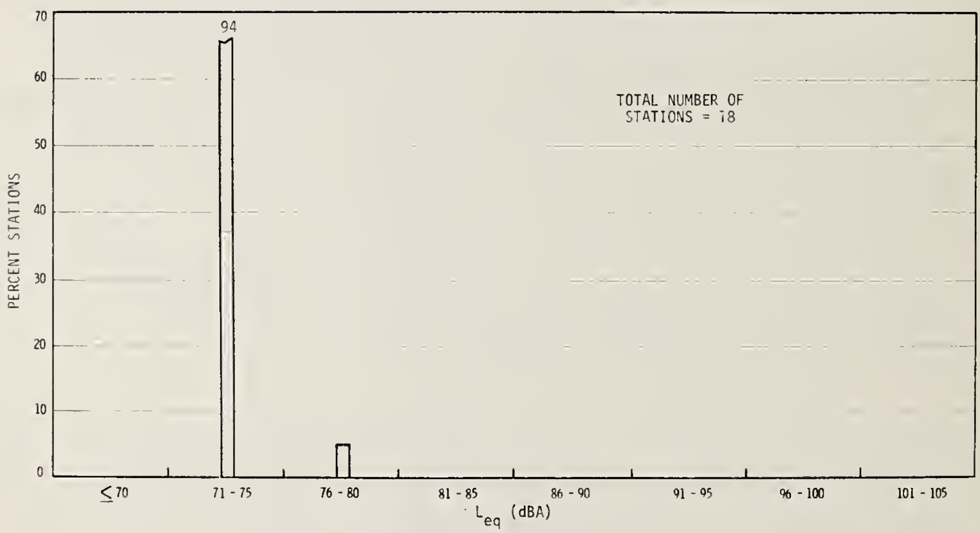



FIGURE D-8 RTA SYSTEM, IN-STATION EQUIVALENT SOUND LEVELS

### D.3.2 In-Station Noise Exposure

The distribution of patronage by station $L_{eq}$ levels for the RTA system is shown in Figure D-9. Equivalent levels of 71 to 75 dBA characterize the station noise environments experienced by 96 percent of the system patronage.

### D.3.3 Comparison of RTA Station $L_A$(Max) with APTA Goals

As shown in Figure D-10, half of the RTA stations have $L_A$(Max) levels which are within five dBA of the APTA goals for those types of stations. Seven of these nine stations are in cuttings. Possible explanations for the relatively low levels are that RTA in-cut stations are often in large, open right-of-way areas without reflective surfaces which produce higher levels. The $L_A$(Max) for the Public Square and Windermere Stations meet the APTA goals probably because of the low speeds and microphone placement discussed above. The remaining 50 percent of the stations register six to ten dBA above the APTA goals.

## D.4 RTA WAYSIDE NOISE

### D.4.1 $L_A$(Max)

The A-weighted maximum pass-by levels, $L_A$(Max), at 15 m (50 ft) from the near track center-line range from 84 to 99 dBA. Figures D-11 and D-12 show the distribution of these $L_A$(Max) levels as a percentage of residential and non-residential wayside mileages, respectively. The recorded levels are very high, considering there is no steel elevated track on the RTA system. Approximately 93 percent of the residential areas, and 97 precent of the non-residential areas, are adjacent to at-grade or open-cut track, where $L_A$(Max) levels of 99 and 93 dBA, respectively, are recorded.

The high $L_A$(Max) levels observed along the wayside of the Airport Line may be attributed to the track gauge on the line, which is 6.4 mm (.25 in.) tighter than standard railroad gauge, although the wheel gauge is set for standard track gauge.

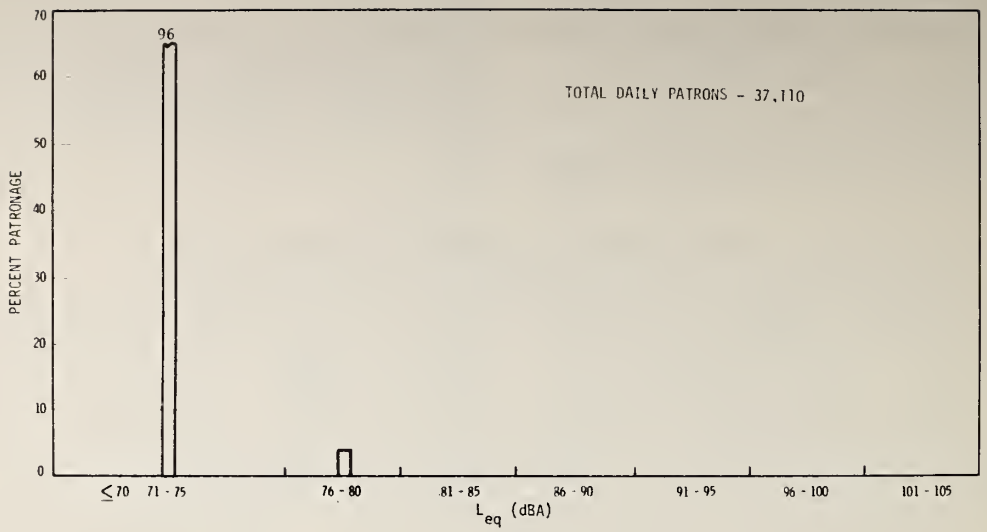



FIGURE D-9 RTA SYSTEM, IN-STATION NOISE EXPOSURE

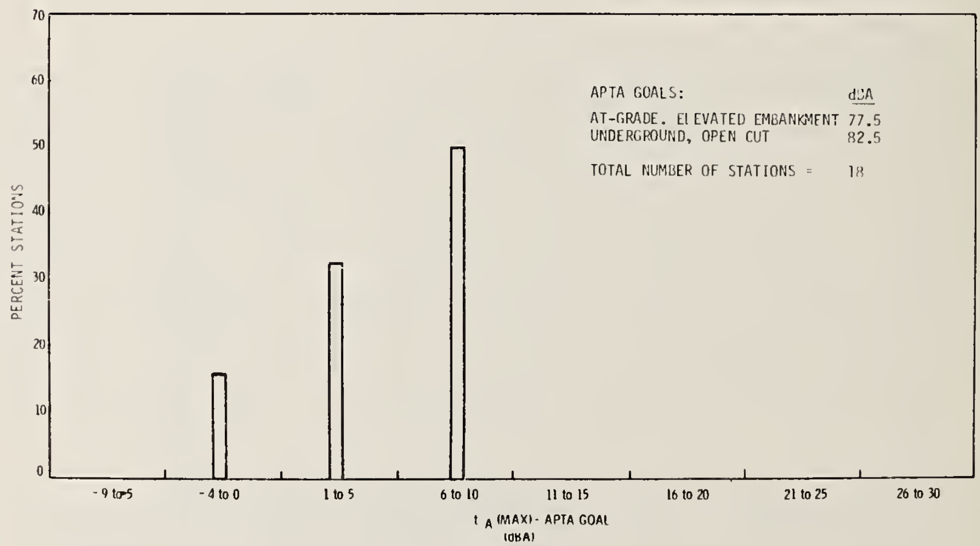



FIGURE D-10 RTA SYSTEM, IN-STATION NOISE GUIDELINE COMPARISON

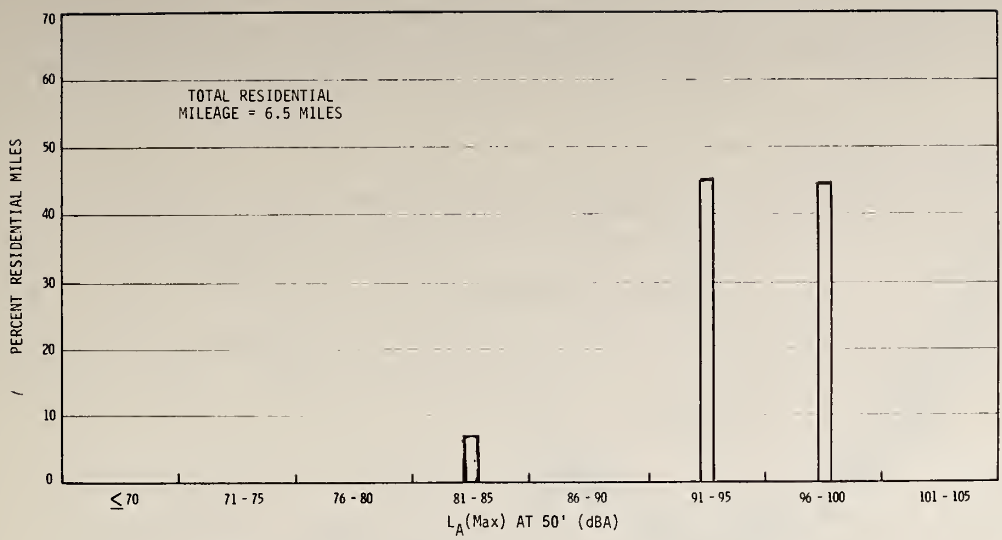



FIGURE D-11 RTA SYSTEM, DISTRIBUTION OF RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

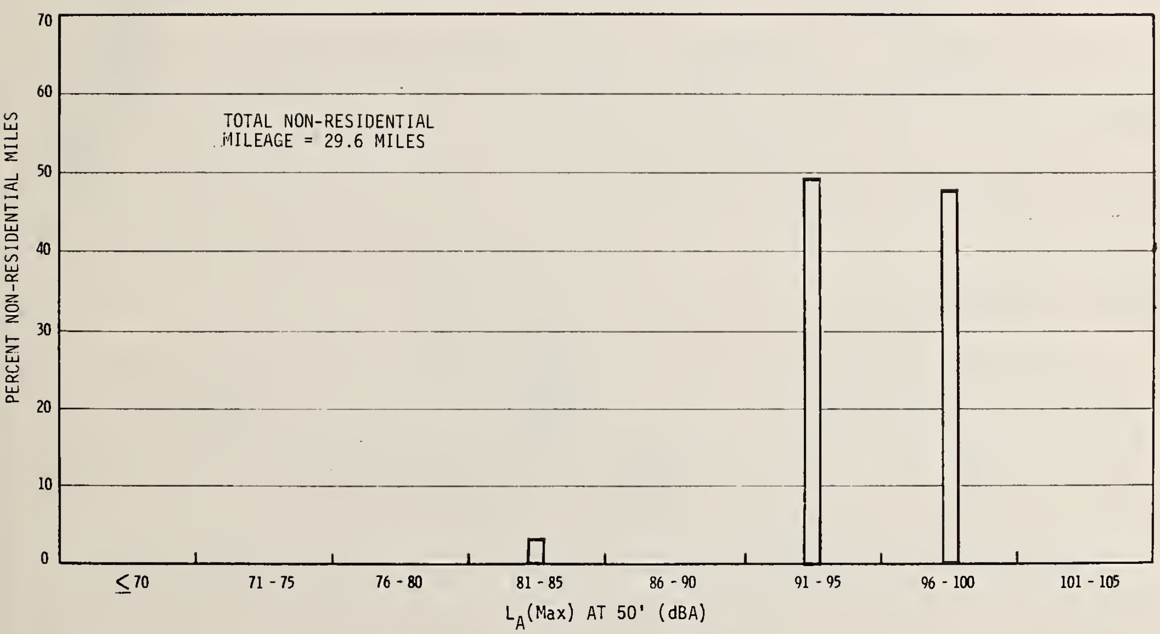



FIGURE D-12 RTA SYSTEM, DISTRIBUTION OF NON-RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

The lowest $L_A$(Max) level, 84 dBA, occurs alongside the elevated embankment track. This level is primarily due to the low operating speeds of cars at the measurement site, approximately 20 mph, as opposed to nearly 53 mph on the other track sections.

### D.4.2 $L_{dn}$ (Trains)

Wayside equivalent day-night sound levels that result only from train pass-bys, $L_{dn}$ (Trains), are shown in Figure D-13. The distribution of $L_{dn}$ (Trains) is based on the pattern of wayside $L_A$(Max), but it also reflects the number of train pass-bys. The $L_{dn}$ levels range from 63 to 79 dBA, with the lower levels observed alongside elevated embankment track.

Wayside areas adjacent to open-cut track are exposed to $L_{dn}$(Trains) levels of 72 and 73 dBA, while those communities abutting at-grade trackage experience levels of 78 and 79 dBA. The one dBA difference is due to 18 additional peak hour train pass-bys over the western segments of the RTA Rapid Route.

### D.4.3 $L_{dn}$ (Ambient)

The average $L_{dn}$ (Ambient) level that results from all noise sources other than train pass-by noise, which is used to characterize the noise environment for wayside communities is 63.3 dBA for the RTA system. $L_{dn}$ (Ambient) levels for residential areas range from 61 to 68 dBA.

### D.4.4 Relative $L_{dn}$

The distribution of Relative $L_{dn}$, which measures the difference between $L_{dn}$ (from all sources of noise) and $L_{dn}$(Ambient), is shown in Figure D-14, and reflects both the pattern of $L_{dn}$(Trains) (Figure D-13) and the $L_{dn}$ (Ambient) levels.

The RTA system experiences Relative $L_{dn}$ levels which range from two to 18 dBA, with a mean level of 11.9 dBA. The high Relative $L_{dn}$ levels (14 to 18 dBA) are found in communities adjacent to at-grade track (comprising nearly 46 percent of the residential

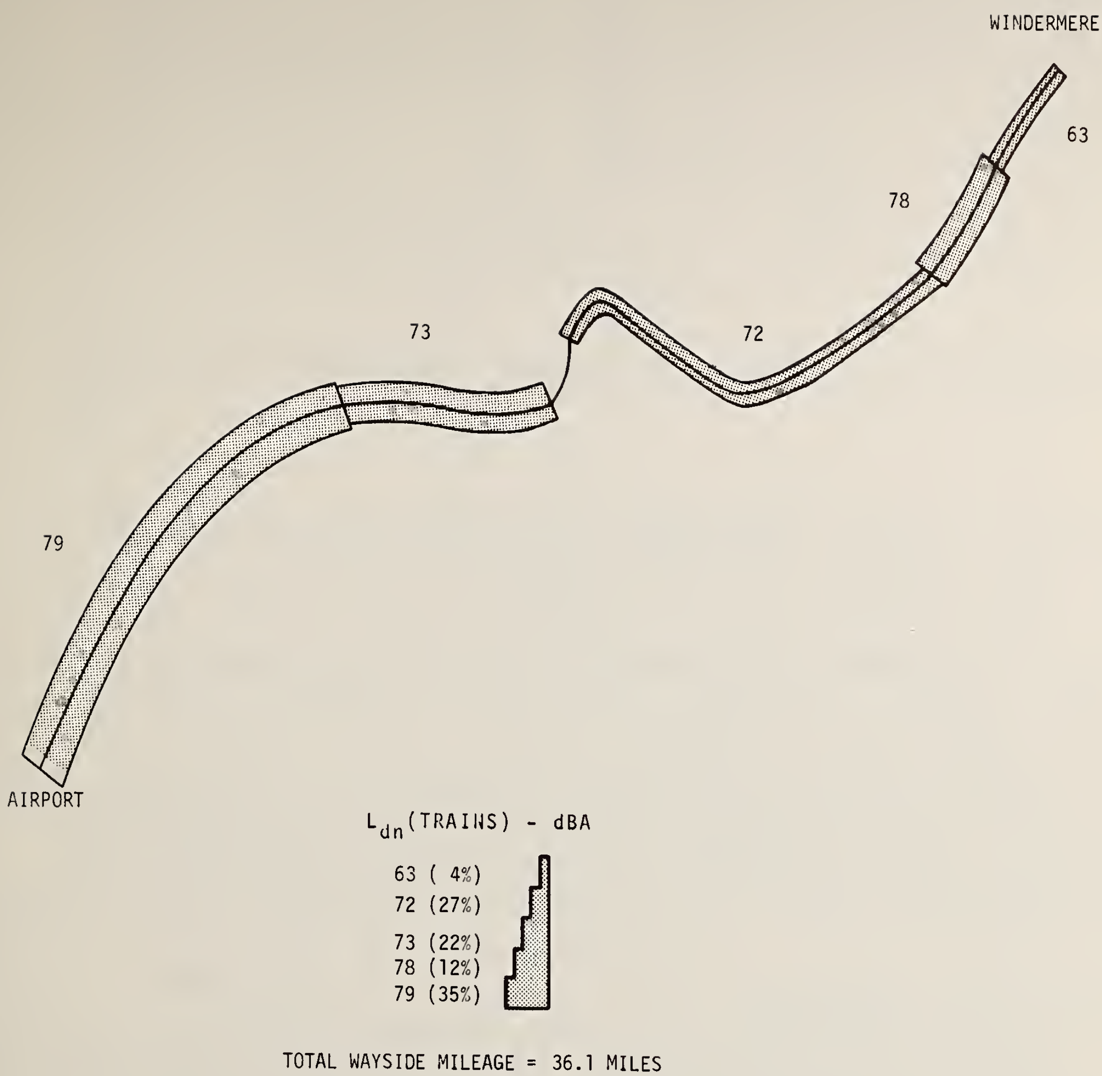



FIGURE D-13 RTA SYSTEM, WAYSIDE $L_{dn}$(TRAINS)

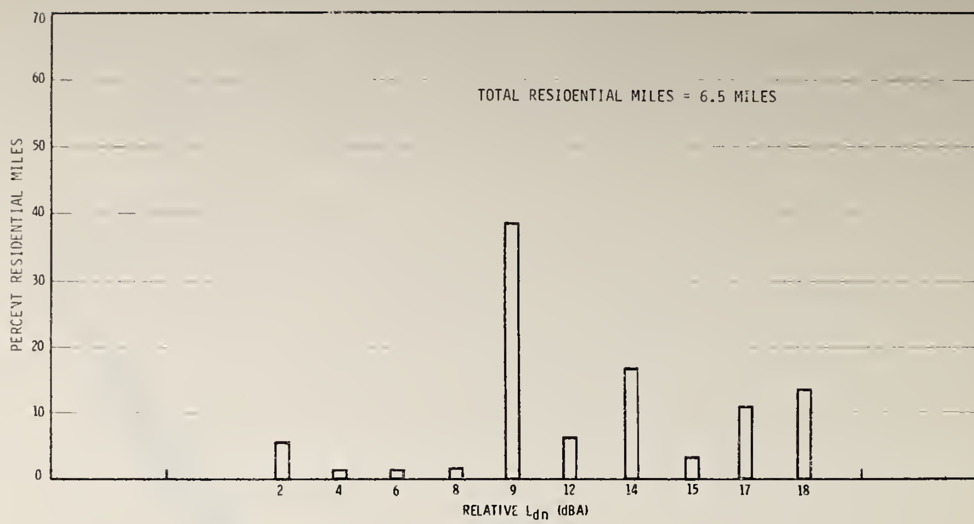



FIGURE D-14 RTA SYSTEM, DISTRIBUTION OF WAYSIDE RELATIVE $L_{dn}$

mileage). In these communities, very high $L_{dn}$(Trains) levels, 78 and 79 dBA, combine with medium $L_{dn}$(Ambient) levels of 61 and 64 dBA. Wayside areas adjacent to open-cut track (47 percent of the residential mileage) are exposed to Relative $L_{dn}$ levels of six to 12 dBA. Medium $L_{dn}$(Ambient) levels (61 to 68 dBA) are found in these communities, where high $L_{dn}$(Trains) levels (72 and 73 dBA) are recorded. The low Relative $L_{dn}$ levels, two to four dBA, occur alongside elevated embankment track, and these residential areas experience medium ambient (61 and 64 dBA) and medium trains (63 dBA) levels.

### D.4.5 Wayside Exposure

The total population residing within the 60-m (200-ft) corridor adjacent to the aboveground segments of RTA is estimated to be approximately 2852. The majority of the population, 92 percent, resides in communities where the higher Relative $L_{dn}$ levels are recorded (55 percent alongside open-cut track and 37 percent adjacent to at-grade track).

Figure D-15 illustrates the distribution of the percent total population within the 60m (200-ft) corridor against Relative $L_{dn}$. It can be seen that approximately 87 percent of the total population is exposed to levels of nine dBA or higher, with only 7 percent exposed to levels of three dBA or lower.


FIGURE D-15 RTA SYSTEM, WAYSIDE NOISE EXPOSURE

### D.4.6 Comparison of CTS Wayside $L_A$(Max) with APTA Guidelines

The distribution of $L_A$(Max) levels relative to the APTA guidelines for residential and non-residential areas adjacent to the rail right-of-way is shown in Figure D-16. None of the residential communities has an $L_A$(Max) level within five dBA of the APTA goals, and only seven percent have levels within 10 dBA of the guidelines. In the case of the non-residential areas, only 3 percent of the $L_A$(Max) levels are within ten dBA of the APTA guidelines.

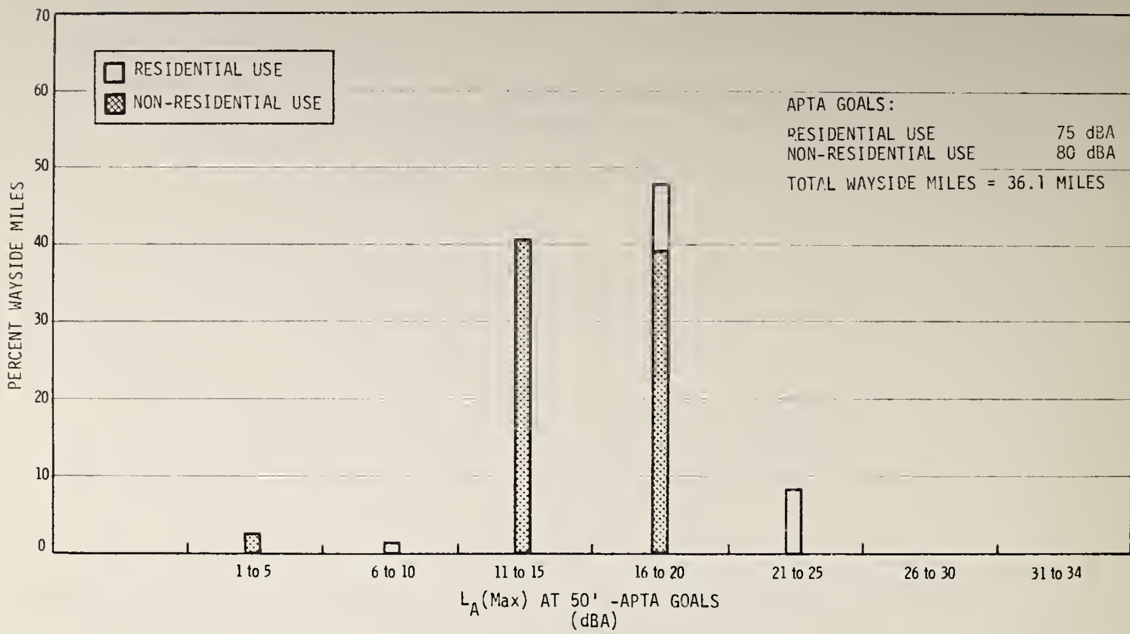



FIGURE D-16 RTA SYSTEM, WAYSIDE NOISE GUIDELINE COMPARISON

# APPENDIX E - URBAN RAIL NOISE ASSESSMENT OF BART SYSTEMS

## E.1 SYSTEM DESCRIPTION (See Table E-1)

The Bay Area Rapid Transit system (BART) consists of four branches in the San Francisco Bay Area: Fremont, Concord, Richmond, and Daly City (Figure E-1). In this report the branches have been divided into two lines: the Daly City-Concord Line extending in a generally northeast-southwest direction, and the Richmond-Fremont Line extending northwest-southeast.

Train operations, however, operate along three system routes: Daly City-Concord, Richmond-Fremont, and Daly City-Fremont.

The BART system is more than 112 km (70 mi) long, of which 39 percent is at-grade or on earth embankment, 33 percent on aerial trackage and 28 percent underground, either in subway or tunnel. All rail is continuous-welded. The roadbed on at-grade sections is ballast and tie, and on concrete aerial structures and subways the rail is directly mounted using resilient fasteners.

### E.1.1 Stations

Of the 34 stations, the majority (62 percent) are center platform, with side platform (29 percent) also represented. Of the three remaining stations, two are bi-level and one is four-tracked with two center platforms. The 34th station, Embarcadero, on the Daly City-Concord Line, was completed after the noise measurements were taken. Sound absorption treatment is included in all subway stations.

### E.1.2 Transit Vehicles

The transit fleet consists of 400 Rohr-built rail vehicles, all acquired for or since the inauguration of service in 1972. These can be grouped into two different car types, designated "A" and "B." The "A" configuration includes an operator's cab and automatic train operation, the "B" configuration does not. In all

TABLE E-1 BART SYSTEM SUMMARY (1 OF 3)

| | RICHMOND-FREMONT | DALY CITY-CONCORD | BART TOTAL[1] |
|---|---|---|---|
| A. ROUTE PHYSICAL | | | |
| 1. Length | 36.1 Miles | 36.4 Miles | 70.4 Miles |
| 2. Track Type | | | Welded Rail; Ballast and Wood Ties; Rail Mounted onto Concrete Trackbed |
| 3. Track Structure Mileage | | | |
| a. Underground | 5.3 Miles | 15.4 Miles | 19.7 Miles |
| b. Concrete Elevated | 16.9 Miles | 6.1 Miles | 23.0 Miles |
| c. At-Grade | 13.9 Miles | 14.9 Miles | 27.7 Miles |
| 4. Number of Stations | 18 | 19 | 34[2] |
| B. VEHICLES | | | |
| 1. Year Manufactured | | | 1972 or later |
| 2. Number in Service | | | 450 |
| 3. Acoustical Treatment | | | Yes |
| C. SYSTEM SCHEDULING | | | |
| 1. Running Time | 56 Minutes | 59 Minutes | |
| 2. Average Running Speed | 72 mph | 72 mph | 72 mph |

TABLE E-1 BART SYSTEM SUMMARY (2 OF 3)

| | RICHMOND-FREMONT | DALY CITY-CONCORD | BART TOTAL[1] |
|---|---|---|---|
| D. POPULATION DATA | | | |
| 1. Daily Ridership | 42,030/day | 76,760/day | 118,790/day |
| 2. Wayside Population Density (Mean) | 10,440/sq.mi. | 7,250/sq.mi. | 9,165/sq.mi. |
| 3. Wayside Population Within 200 Ft. | 6,900 persons | 3,230 persons | 9,800 persons |
| 4. Residential Land Use (Length - % of Total Wayside) | 15.5 Miles (37.0%) | 23.3 Miles (37.9%) | 37.9 Miles (37.4%) |
| E. IN-CAR SOUND LEVELS | | | |
| 1. Average Inter-Station $L_A$(Max) | 79.3 dBA | 81 dBA | 80 dBA |
| 2. $L_A$(Max) Standard Dev. | 3.12 dBA | 3.38 dBA | 3.32 dBA |
| 3. $L_{eq}$(R) | 75.9 dBA | 78.6 dBA | |
| F. IN-STATION SOUND LEVELS | | | |
| 1. Average Station $L_A$(Max) | 80.4 dBA | 79.7 dBA | 80 dBA |
| 1.5 Range of $L_A$(Max) | 76-85 dBA | 76-82 dBA | 76-85 dBA |
| 2. Average station $L_{eq}$ | 68.8 dBA | 69.5 dBA | 69.2 dBA |

TABLE E-1 BART SYSTEM SUMMARY (3 OF 3)

| | RICHMOND-FREMONT | DALY CITY-CONCORD | BART TOTAL[1] |
|---|---|---|---|
| G. WAYSIDE COMMUNITY SOUND LEVELS | | | |
| 1. Average $L_A$(Max) @ 50' | 88.7 dBA | 87.4 dBA | 88.2 dBA |
| 1.5 $L_A$(Max) Range @ 50' | 86-91 dBA | 86-91 dBA | 86-91 dBA |
| 2. Average $L_{DN}$(Trains) | 68.9 dBA | 68.0 dBA | 68.5 dBA |
| 3. Average $L_{DN}$(Ambient) | 61.4 dBA | 58.2 dBA | 60.1 dBA |
| 4. Average Relative $L_{DN}$ | 8.8 dBA | 10.6 dBA | 9.2 dBA |

NOTES:

1. Overlapping track sections only counted once.
2. 34th Station, Embarcadero, opened after the noise measurements were conducted.


FIGURE E-1 BART RAIL TRANSIT LINES

other respects the two are identical. Each car is 21.3 m (70 ft) long, with a seating capacity of 72 passengers.

The rail vehicles incorporate several noise control features. The car body is sound-insulated and air conditioned; it is constructed with light-weight trucks and rubber mounts; it has inserts for vibration isolation; and it is equipped with a low noise braking system. Wheel grinders and lathes are used for maintaining wheels in smooth condition.

E.1.3 Route Description (See Figures E-2, E-3)

The Daly City-Concord Line begins in northern San Mateo County, traveling briefly over at-grade 1.8 km (1.1 mi) and aerial track, 1.6 km (1.0 mi). However, most of the line to Oakland is underground, 17.1 km (10.7 mi), passing through San Francisco County to the Transbay tubes under San Francisco Bay. An aerial segment of the line leads to Oakland, 2.4 km (1.5 mi), where the line again returns underground for, 2.2 km (1.4 mi). The line then travels along at-grade track to Rockridge Station, 5.8 km (3.6 mi), and then underground, 5.1 km (3.2 mi) to Orinda Station. The remaining segments of the line to the Concord terminus are predominatly aboveground, either at-grade, 16.8 km (10.5 mi) or aerial, 3.8 km (2.4 mi). Approximately 38 percent of the aboveground track is adjacent to residential neighborhoods.

The Richmond-Fremont Line proceeds in a northwesterly direction from the Fremont terminal along aboveground track, at-grade, 16.2 km, (10.1 mi), and aerial, 4.3 km (2.7 mi) to Hayward Station. From there to Fruitvale Station, through Alameda County, the line runs along exclusively aerial track, 14.2 km (8.9 mi). A short at-grade segment, 1.3 km (0.8 mi), leads to an underground section, 5.6 km (3.5 mi) through Oakland. The line then proceeds briefly to aerial track, 1.6 km (1.0 mi), and then returns underground, 5.1 km (3.2 mi) through Berkeley. The remainder of the line to the Richmond terminus is aboveground, either aerial, 7.2 km (4.5 mi) or at-grade, 2.2 km (1.4 mi). Thirty-seven percent of the aboveground track is adjacent to residential areas.

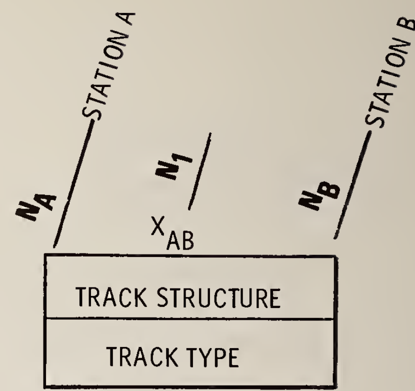
# LEGEND FOR FIGURES E-2 AND E-3

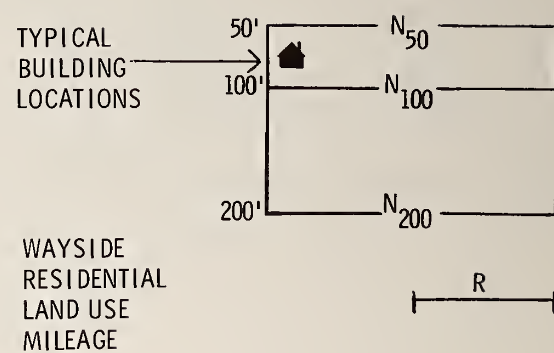
TRACK STRUCTURE

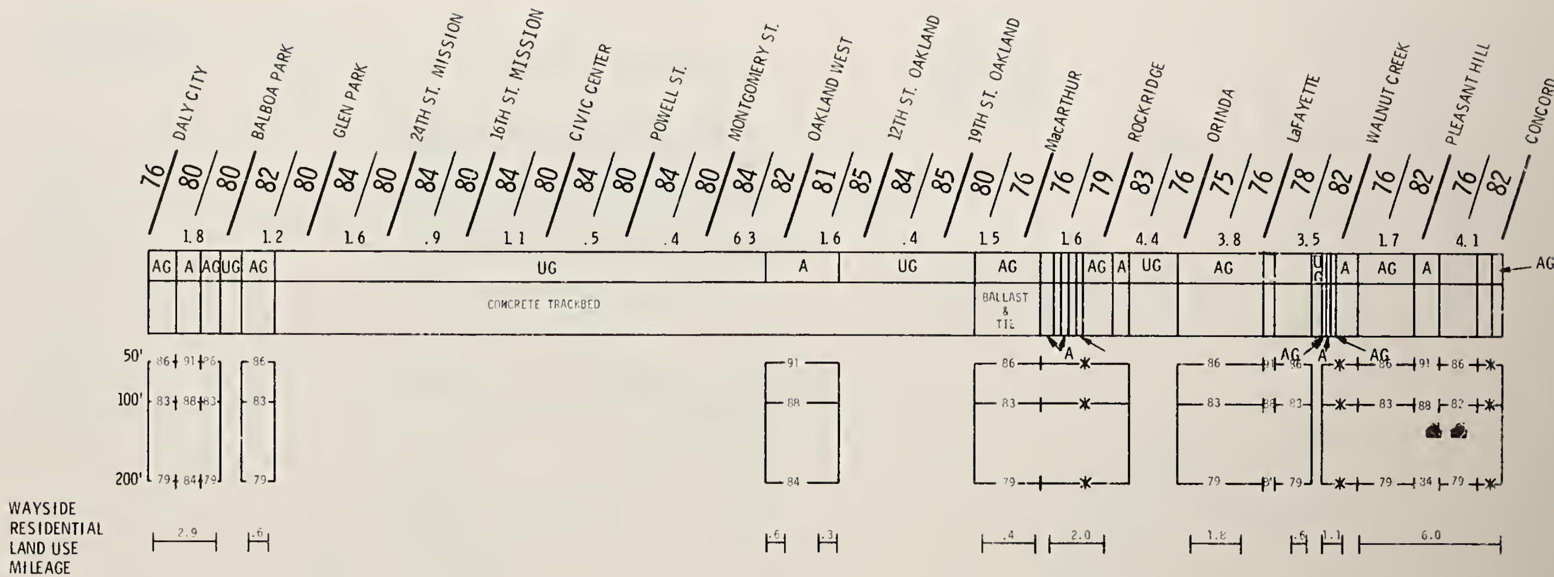
| | | |
|---|---|---|
| ES | = | ELEVATED STEEL |
| EE | = | ELEVATED EMBANKMENT |
| UG | = | UNDERGROUND |
| CV | = | CONCRETE VIADUCT |
| IC | = | IN CUT |
| AG | = | AT GRADE |
| MS | = | MEDIAN STRIP |
| EC | = | ELEVATED CONCRETE |
| A | = | AERIAL |

| | | |
|---|---|---|
| $X_{AB}$ | = | INTERSTATION DISTANCE (MILES) |
| $N_A/N_B$ | = | STATION NOISE AT STATION A/B (dBA) |
| $N_i$ | = | IN-CAR NOISE (dBA) |
| $N_{50}$ | = | WAYSIDE NOISE AT 50 FEET (dBA) |
| $N_{100}$ | = | WAYSIDE NOISE AT 100 FEET (dBA) |
| $N_{200}$ | = | WAYSIDE NOISE AT 200 FEET (dBA) |
| R | = | WAYSIDE RESIDENTIAL LAND USE MILEAGE (BOTH SIDES OF TRACK) |

DATA UNIQUE TO PARTICULAR SYSTEMS ARE NOTED ON SYSTEM SCHEMATICS






*NOTE: SOUND LEVELS ADJACENT TO
ALL SECTIONS OF AERIAL/AT-GRADE
TRACK ARE ASSUMED TO BE IDENTICAL
(SEVERAL BRIDGES NOT SHOWN)

TYPICAL BUILDING LOCATIONS
RESIDENTIAL
NON-RESIDENTIAL

FIGURE E-2 BART SYSTEM, DALY CIT ..NCORD LINE

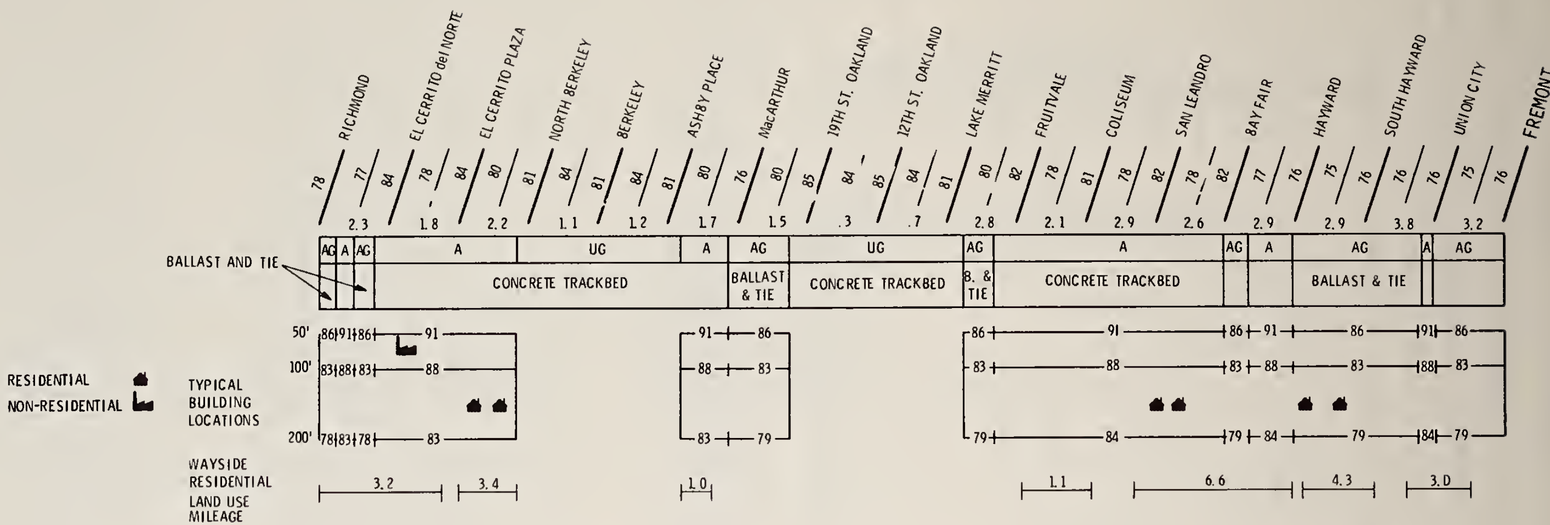



FIGURE E-3 BART SYSTEM, RICHMOND-FREMONT LINE

Running time from Richmond to Fremont is 56 minutes.

All system routes of BART exhibit similar characteristics. The trains currently operate between 5:30 A.M. and midnight, with the exception of the Daly City-Fremont service, which terminates at 6:00 P.M. Headways remain constant throughout the day: 12 minutes on the segments terminating at Concord and Richmond, and six minutes on the segments terminating at Daly City and Fremont. Capacity demands are met by varying the train lengths throughout the day, from two "A" cars during light periods, to two "A" cars and eight "B" cars during peak periods. Nighttime service was initiated late in 1975, after the noise measurements were compiled.

The majority (51 percent) of the BART right-of-way is adjacent to other transportation modes. The percentage breakdown is as follows:

a. 29 percent is adjacent to railroad operations;
b. 14 percent is in a freeway median; and
c. 8 percent abuts freeway mileage.

Train speeds recorded during the noise measurement were at the top speed of BART trains, 128 km/h (80 mph). Present average operating speeds are 115 km/h (72 mph).

## E.2 IN-CAR NOISE

### E.2.1 $L_A$(Max)

In-car noise plateau levels, $L_A$(Max), which exist in the in-car noise environment of the BART system vary according to the type of track being traversed. In-car $L_A$(Max) is lowest when travelling over at-grade track, averaging 75 dBA. $L_A$(Max) levels over aerial track are 78 dBA; on underground track they are 84 dBA.

The distribution of route-miles by $L_A$(Max), Figure E-4, reflects the track structure of the system routes, which has been described above; it is illustrated in Figures E-2 and E-3. Half of the Daly-Concord Line, travelling under the CBD and the trans-bay

tubes, has in-car $L_A$(Max) in the 81 to 85 dBA category. In-car $L_A$(Max) for the majority of the Richmond-Fremont Line is in the 76 to 80 dBA range, representing aerial track.

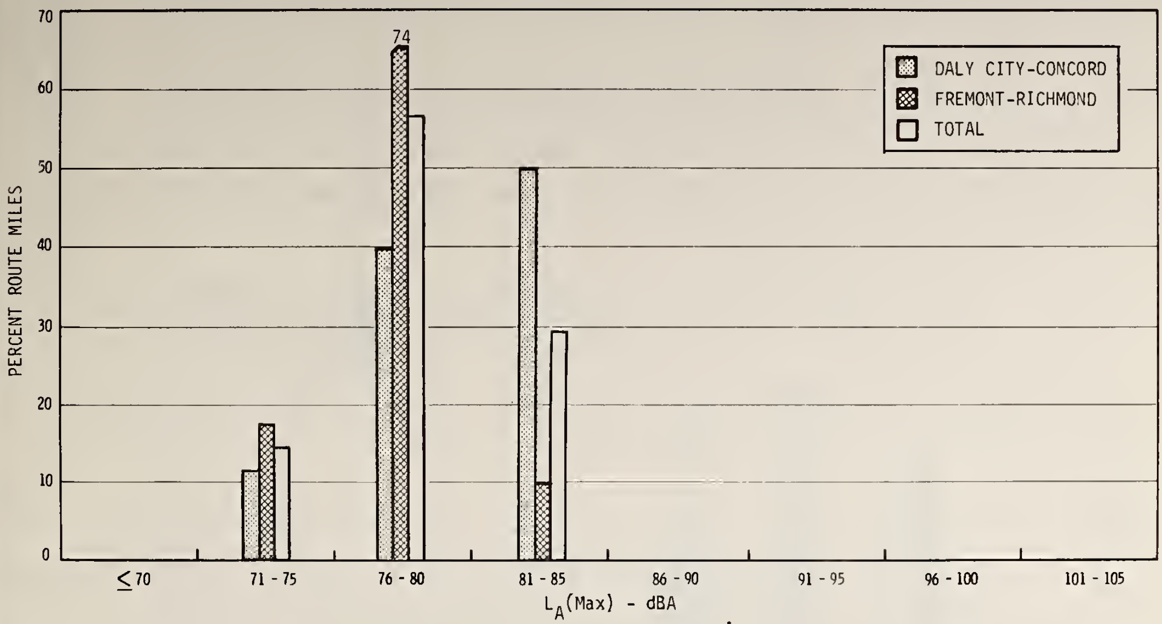



FIGURE E-4 BART SYSTEM, DISTRIBUTION OF IN-CAR PLATEAU NOISE LEVELS

### E.2.2 In-Car Equivalent Noise Levels

Route equivalent levels, $L_{eq}$(R), characterizing the in-car environments for complete end-to-end trips on the Richmond-Fremont and Concord-Daly City Lines, are 75.9 and 78.6 dBA, respectively.

The distribution of route-miles versus inter-station $L_{eq}$, Figure E-5, is similar to the distribution of $L_A$(Max) from which it was derived. In-car noise environments for nearly two-thirds of the BART system had $L_{eq}$ values above 75 dBA.

### E.2.3 In-Car Exposure

Figure E-6 represents an estimate of in-car exposure for BART. The measure, people-hours, was derived by weighting patronage by estimated trip times, and then distributing the resulting measure of ridership over the in-car $L_{eq}$ distribution (see Appendix H for

methodological details). The distribution is fairly evenly distributed between 70 and 85 dBA. Given accurate trip time information for the system (not available for this analysis), one could use this distribution to specify the average time exposed to these $L_{eq}$ levels and the total number of patrons exposed to each level.

### E.2.4 Comparison of BART In-Car $L_A$(Max) with APTA Guidelines

As shown in Figure E-7, in car noise levels for the entire BART system are one to five dBA above the APTA guidelines for the corresponding type of track.

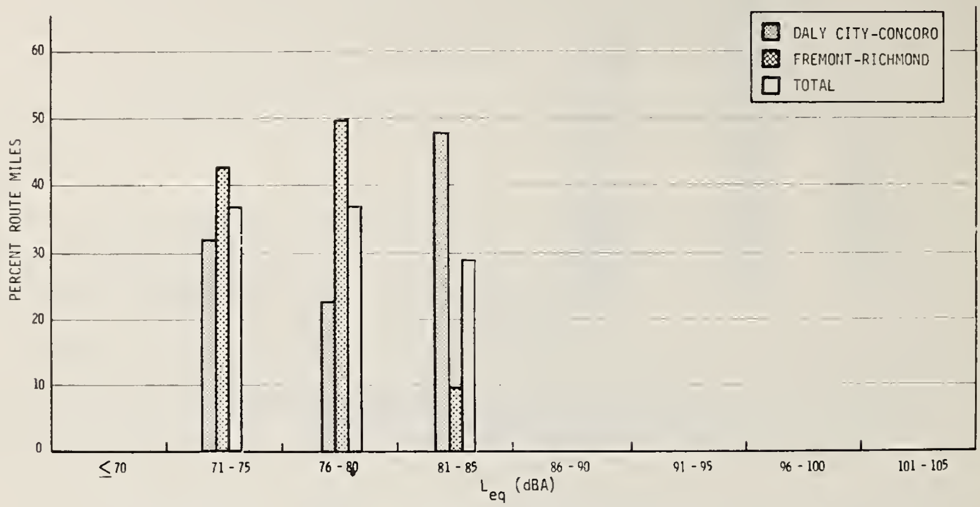



FIGURE E-5 BART SYSTEM, DISTRIBUTION OF IN-CAR EQUIVALENT SOUND LEVELS

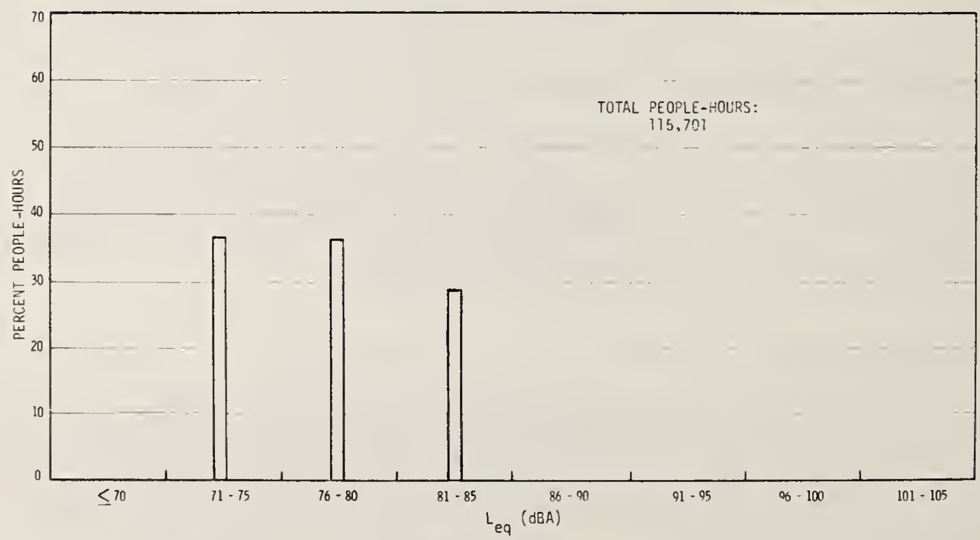



FIGURE E-6 BART SYSTEM, IN-CAR NOISE EXPOSURE

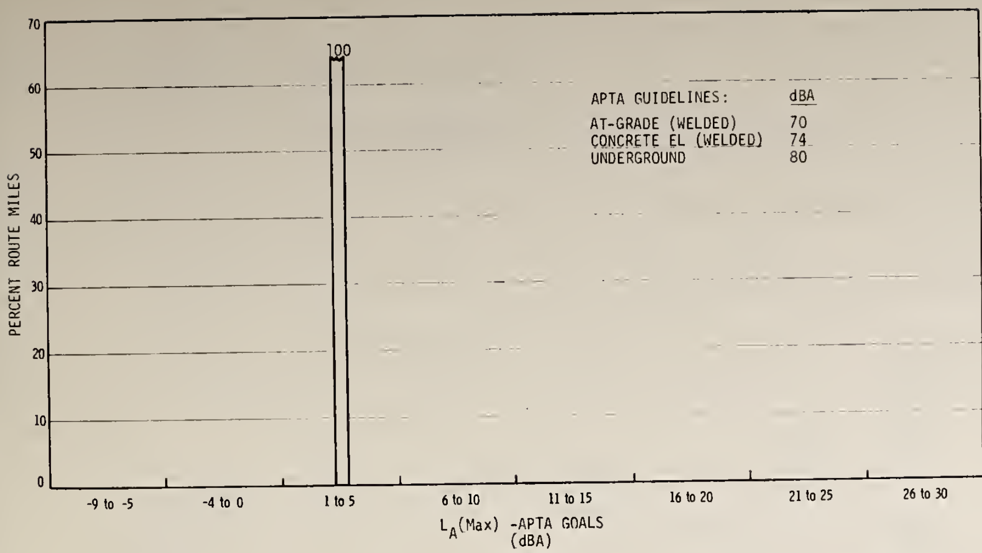



FIGURE E-7 BART SYSTEM, IN-CAR NOISE GUIDELINE COMPARISON

## E.3 STATION NOISE

### E.3.1 $L_A$(Max) and $L_{eq}$ (Figures E-8 and E-9)

Average arrival-departure sound levels for stations on the BART system range from 76 to 85 dBA, with the distribution (shown in Figure E-8) evenly divided between the 76 to 80 and 81 to 85

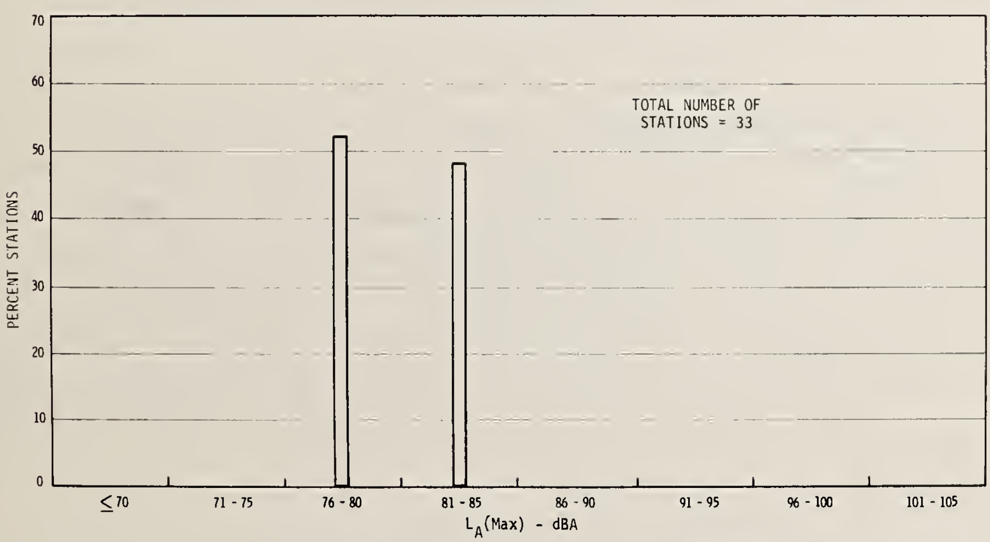



FIGURE E-8 BART SYSTEM, IN-STATION MAXIMUM NOISE LEVELS

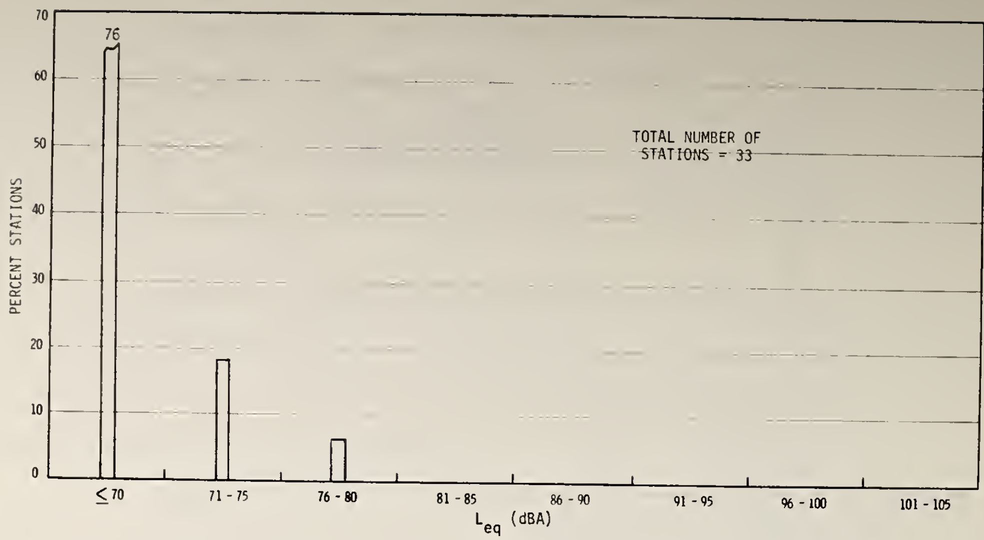



FIGURE E-9 BART SYSTEM, IN-STATION EQUIVALENT SOUND LEVELS

dBA intervals. The $L_A$(Max) levels in underground and elevated (aerial) stations are two to nine dBA above those in at-grade stations. In many cases, acoustical treatment in underground stations reduces noise levels below those in aerial stations. Among stations on the same track type, center platform stations have slightly lower $L_A$(Max) levels.

Figure E-9 shows that in 76 percent of BART stations the $L_{eq}$ levels are determined to be less than or equal to 70 dBA. The two stations with $L_{eq}$ above 75 dBA, Rockridge and Walnut Creek, are among those in which actual $L_{eq}$ measurements were taken. In both stations, noise sources other than train arrivals and departures contributed significantly to the $L_{eq}$ (freeway noise in Rockridge and public address system noise in Walnut Creek). The $L_{eq}$ levels for stations which were not measurement sites were extrapolated, based on the magnitude and frequency of arrival-departure levels and thus do not account for any unusually high background noise sources. The shorter headway times on the Daly City and Fremont branches result in $L_{eq}$ levels which differ from the average $L_A$(Max) level by a smaller margin than is the case on the Richmond and Concord branches.

## E.3.2 In-Station Noise Exposure

The distribution of patronage versus station $L_{eq}$ levels for each line of BART is shown in Figure E-10. The heavy patronage in underground stations on the Daly City-Concord Line is reflected in the interval of $L_{eq}$ values less than or equal to 70 dBA. The majority of patronage on the Fremont-Richmond Line is also exposed to in-station $L_{eq}$ of less than or equal to 70 dBA, but the total daily patronage on this line is only 35 percent of the BART system patronage.

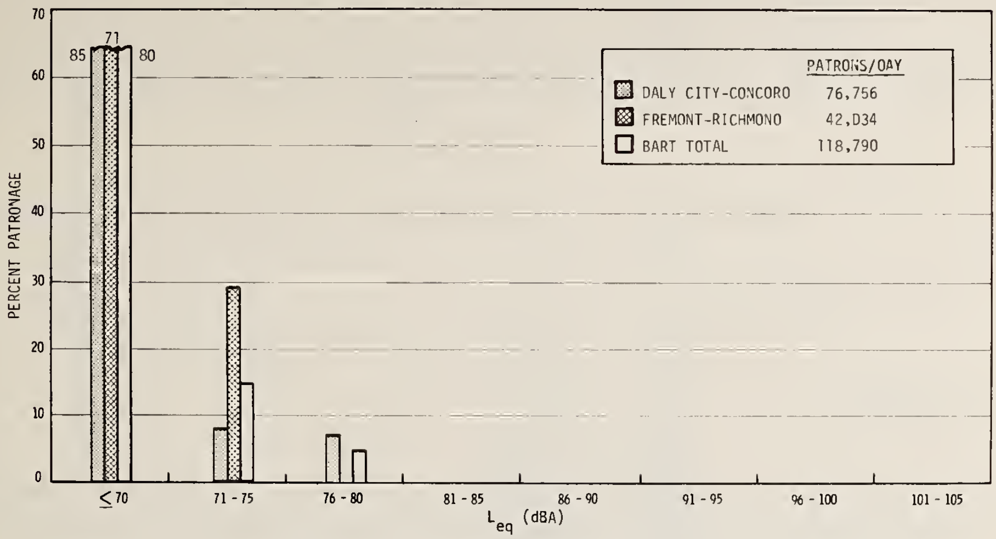



FIGURE E-10 BART SYSTEM, IN-STATION NOISE EXPOSURE

## E.3.3 Comparison of BART Station $L_A$(Max) with APTA Guidelines

As shown in Figure E-11, $L_A$(Max) levels in 85 percent of the BART stations are at or below the APTA guidelines for station noise. All underground stations other than those in Oakland have levels in this range, along with all but one of the at-grade stations. Most of the aerial stations have levels one to five dBA above the APTA guidelines.

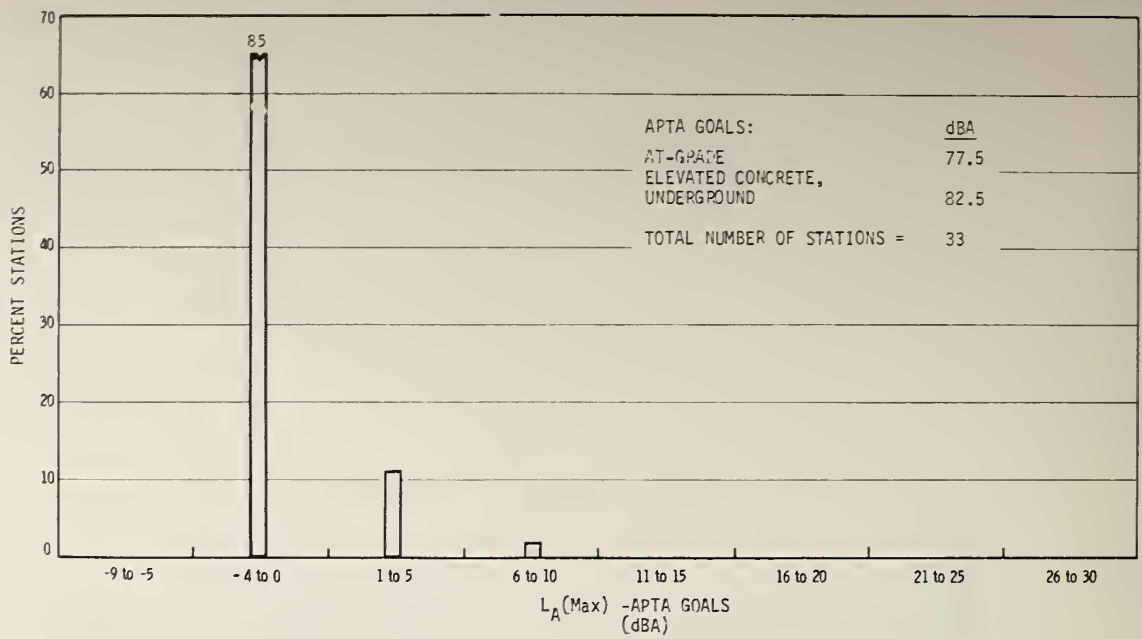



FIGURE E-11 BART SYSTEM, IN-STATION NOISE GUIDELINE COMPARISON

## E.4 BART WAYSIDE NOISE

### E.4.1 $L_A$(Max)

The average A-weighted maximum pass-by level, $L_A$(Max), at 15 m (50 ft) from the near track center-line was determined from wayside measurements taken at selected sites along both lines. $L_A$(Max) levels of 86 dBA and 91 dBA were recorded adjacent to at-grade and aerial track, respectively.

Train speeds for the pass-bys for which $L_A$(Max) was measured were reported to be the maximum operating speed of BART, 80 miles per hour. Present operating speeds are approximately 72 miles per hour. Using a relationship between speed and $L_A$(Max) derived as part of the BART Impact Program,* one can determine that the present operating speeds would result in $L_A$(Max) levels of approximately one dBA less than the average measured $L_A$(Max) used in this analysis.

*Bolt, Beranek and Newman, Inc. "Impacts of BART - Interim Service Findings," TM 16-4-76, DOT-OS-30176, March 1976, p. 20.

The distributions of the percentage of residential and non-residential wayside experiencing each $L_A$(Max) level are given in Figures E-12 and E-13, for the Daly City-Concord Line, the Richmond-Fremont Line, and the entire BART system. The majority of wayside areas (both residential and non-residential) along the Daly City-Concord Line are along at-grade track with an $L_A$(Max) at 15 m (50 ft) of 86 dBA. The opposite distribution exists along the Richmond-Fremont Line, with the majority of wayside areas, particularly residential, along aerial track with $L_A$(Max) at 15 m (50 ft) of 91 dBA. Of the entire BART system slightly more residential wayside area is along aerial track. Nearly 65 percent of the non-residential area, however, is along at-grade track.

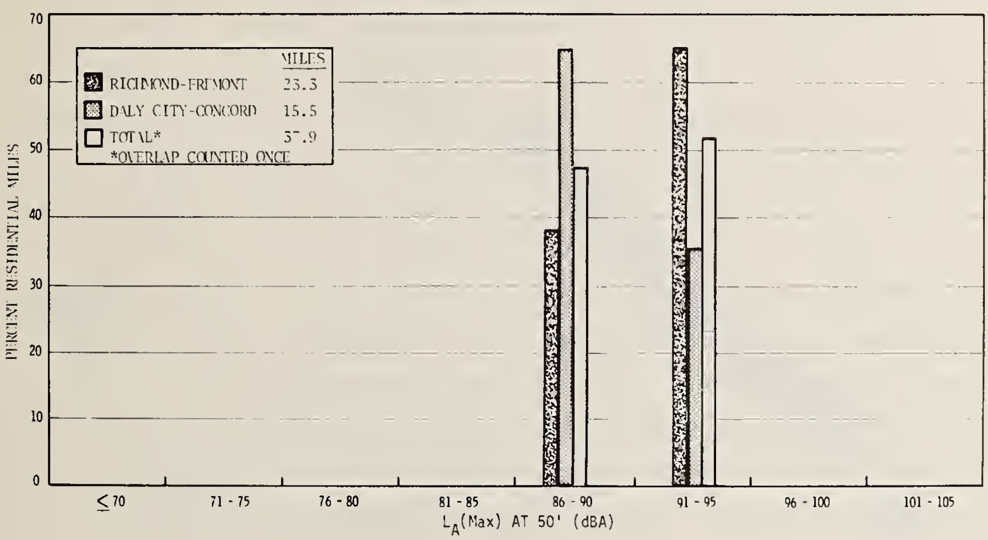



FIGURE E-12 BART SYSTEM, DISTRIBUTION OF RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

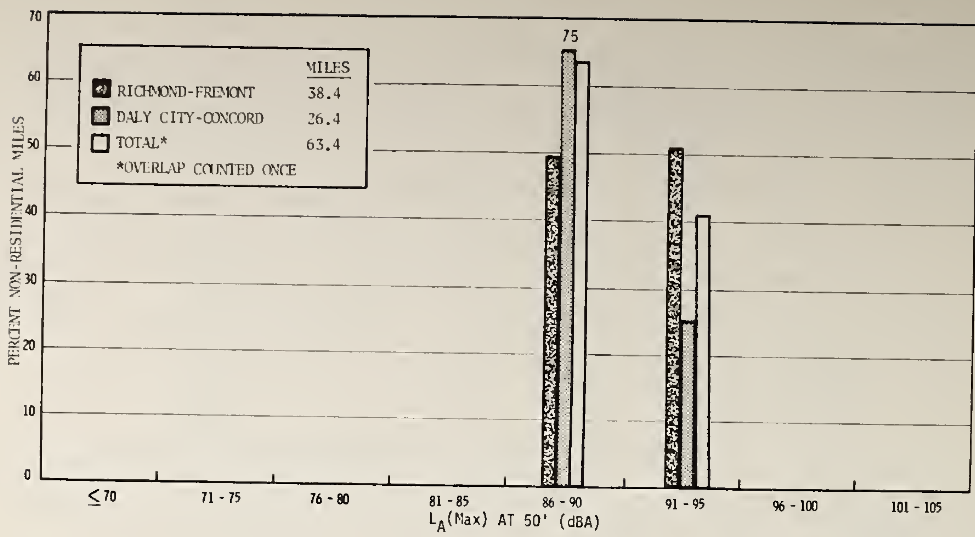



FIGURE E-13 BART SYSTEM, DISTRIBUTION OF NON-RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

For consistency with the wayside $L_A$(Max) analysis for the other six systems, the BART wayside $L_A$(Max) distributions were based on generalized track structure classifications of either aerial or at-grade. If the track structure had been further broken down to identify short-length crossovers, the $L_A$(Max) distribution would include a portion of the wayside experiencing lower sound levels resulting from train pass-bys (i.e., 78 dBA at 15 m (50 ft) from at-grade crossovers). However, this difference in $L_A$(Max) is attributed to lower speeds over the crossovers, and for this analysis it was assumed that speeds were constant for the entire system.

### E.4.2 $L_{dn}$ (Trains)

The equivalent day-night sound levels that result only from train pass-bys, $L_{dn}$(Trains), are illustrated in Figure E-14. As a measure of exposure, the distribution of $L_{dn}$(Trains) levels reflects both the $L_A$(Max) pattern described previously, and the number and duration of train pass-bys.

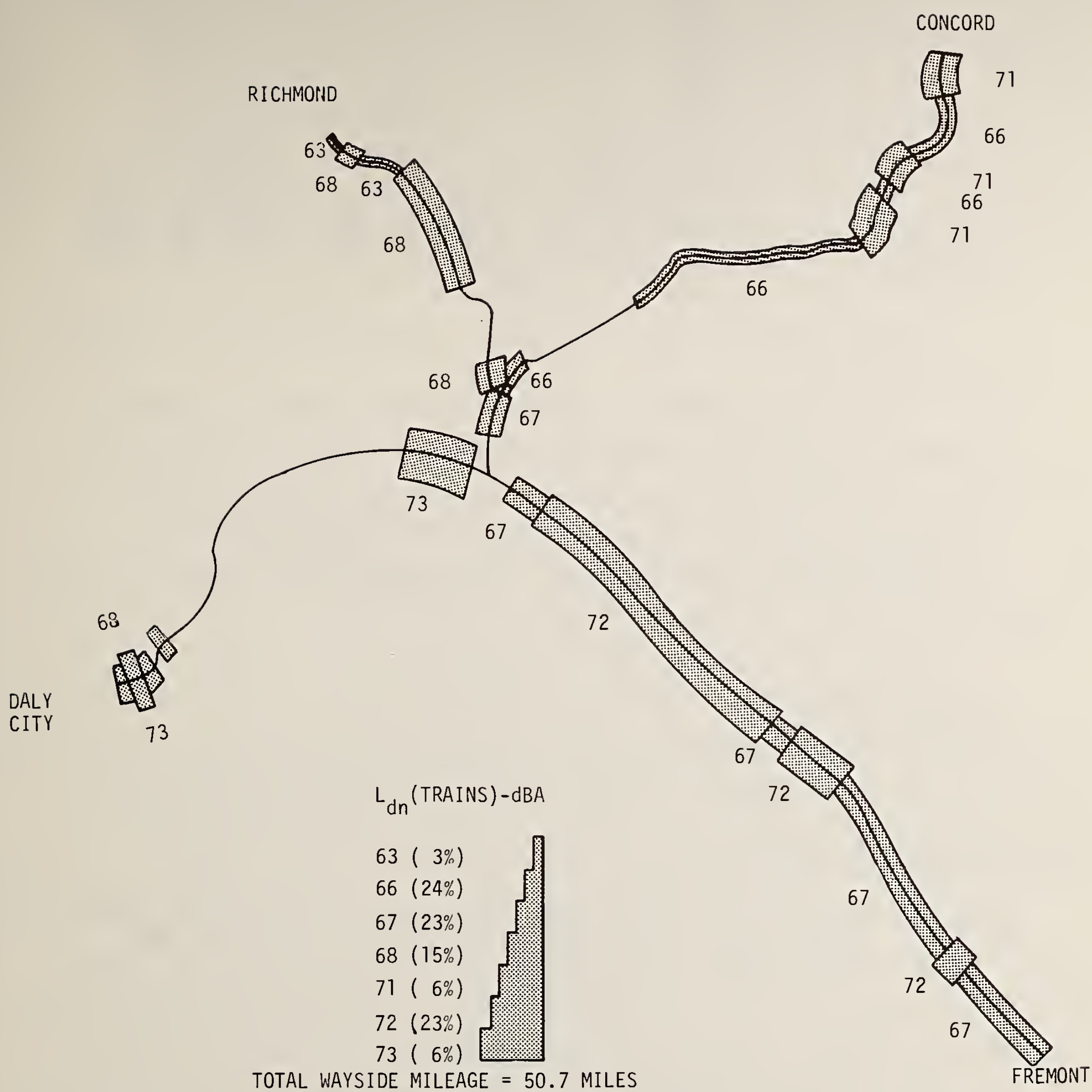



FIGURE E-14 BART SYSTEM, WAYSIDE $L_{dn}$ (TRAINS)

On each branch, the higher $L_{dn}$(Trains) levels are observed adjacent to aerial track, and are consistently five dBA higher than levels recorded alongside at-grade track.

The effect of train pass-bys is clearly seen upon examination of the total BART system. On the two southernmost branches, $L_{dn}$(Trains) levels alongside at-grade track are 67 and 68 dBA; adjacent to aerial structures, they are 72 and 73 dBA. Both branches are served by two sets of train operations (see the System Description above). Conversely, the northern segment of the Richmond-Fremont Line has the lowest $L_{dn}$(Trains) levels (63 dBA on at-grade track and 68 dBA on aerial track). This branch has significantly fewer pass-bys per day.

### E.4.3 $L_{dn}$ (Ambient)

The average $L_{dn}$ (Ambient) levels which are used to characterize the noise levels of wayside communities resulting from all noise sources other than train pass-bys, are 58.2 dBA for the Daly City-Concord Line, and 61.4 dBA for the Richmond-Fremont Line. The average $L_{dn}$ (Ambient) for the entire BART system wayside is 60.1 dBA.

### E.4.4 Relative $L_{dn}$

The distribution of percent wayside residential mileage by Relative $L_{dn}$, illustrated in Figure E-15, reflects both the pattern of $L_{dn}$(Trains) shown in Figure E-14 and the $L_{dn}$(Ambient) distribution discussed earlier.

Relative $L_{dn}$ levels on the BART system range from two dBA to 19 dBA, with a mean level of 9.2 dBA. The Richmond-Fremont and Daly City-Concord Lines have mean Relative $L_{dn}$ levels of 8.8 and 10.6 dBA, respectively.

Low Relative $L_{dn}$ levels (two to five dBA), affecting 25 percent of the residential mileage, are found in communities adjacent to both types of track (59 percent of which abuts aerial track). In these areas, medium $L_{dn}$(Ambient) levels (61 and 64 dBA) combine

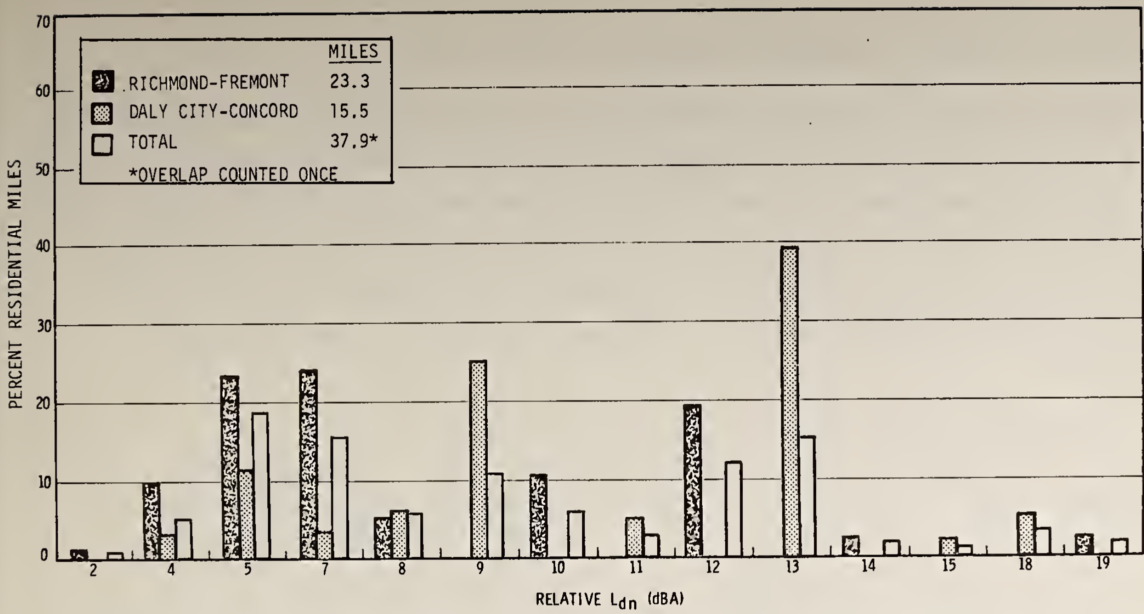



FIGURE E-15 BART SYSTEM, DISTRIBUTION OF WAYSIDE RELATIVE $L_{dn}$

with medium $L_{dn}$(Trains) levels (63 to 68 dBA).

The majority (70 percent) of the residential mileage experiences Relative $L_{dn}$ levels between seven and 15 dBA. Approximately 54 percent of these communities are adjacent to at-grade track, with the remainder alongside aerial track. In the communities abutting at-grade trackage, low (53 and 58 dBA) or medium (61 dBA) $L_{dn}$(Ambient) levels are combined with medium (66 to 68 dBA) $L_{dn}$(Trains) levels. Communities adjacent to aerial track have primarily low (58 dBA) or medium (61 and 64 dBA) ambient levels combining with high trains levels (71 to 73 dBA).

The highest Relative $L_{dn}$ levels (18 and 19 dBA), observed in only five percent of the residential areas, are found exclusively alongside aerial track. Here, a low $L_{dn}$(Ambient) level (53 dBA) is combined with high $L_{dn}$(Trains) levels (71 and 72 dBA).

### E.4.5 Wayside Exposure

The total population residing within the 60 m (200-ft) corridor along aboveground segments of BART is approximately 9800. Two thirds of this total resides in the Richmond-Fremont Line wayside communities, with the remainder in Daly City-Concord Line wayside communities. The wayside along the former line has more residen-

tial areas as well as higher wayside densities.

The distribution of the percent population against the Relative $L_{dn}$ levels is shown in Figure E-16. More than 45 percent of the wayside population lives in areas with Relative $L_{dn}$ levels less than or equal to five dBA, and only 16 percent is exposed to levels greater than ten dBA. The remaining population resides in communities where Relative $L_{dn}$ levels of seven to ten dBA are observed.

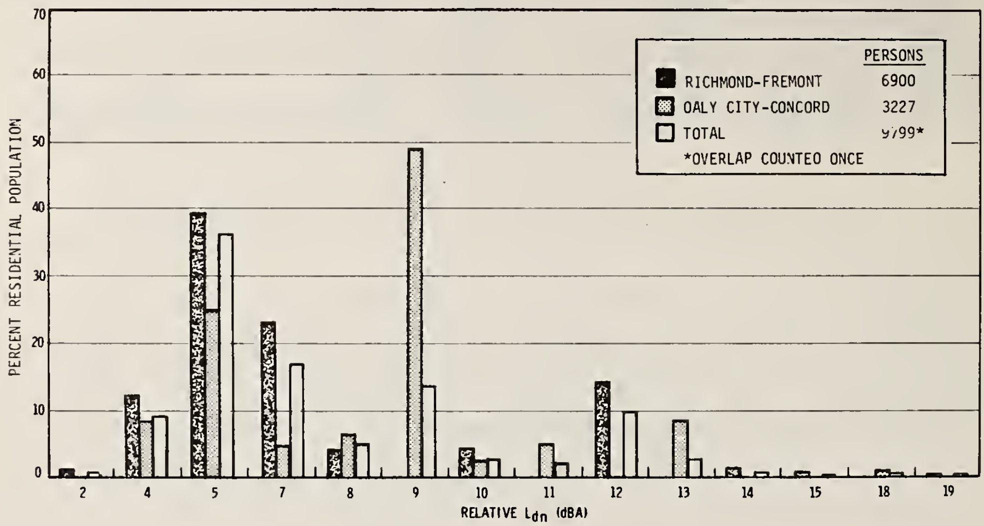



FIGURE E-16 BART SYSTEM, WAYSIDE NOISE EXPOSURE

### E.4.6 Comparison of BART Wayside $L_A$(Max) with APTA Guidelines

Figure E-17 illustrates distributions of wayside $L_A$(Max) at 15 m, (50 ft), relative to the APTA guidelines for $L_A$(Max) at the face of the building of residential and non-residential areas abutting the rail right-of-way. All of the BART wayside $L_A$(Max) levels exceed the APTA guidelines, with residential areas with $L_A$(Max) levels 16 dBA greater than the guidelines, comprising nearly 20 percent of the wayside. If this comparison were made for $L_A$ (Max) levels at building line distances of 60 m (200 ft), all the wayside $L_A$(Max) levels would be within ten dBA of the APTA goal. This may be a more appropriate comparison in the case of BART

than for other properties since the BART right-of-way was located after the establishment of land use boundaries, and thus more buffering may have been provided than in many of the older systems.

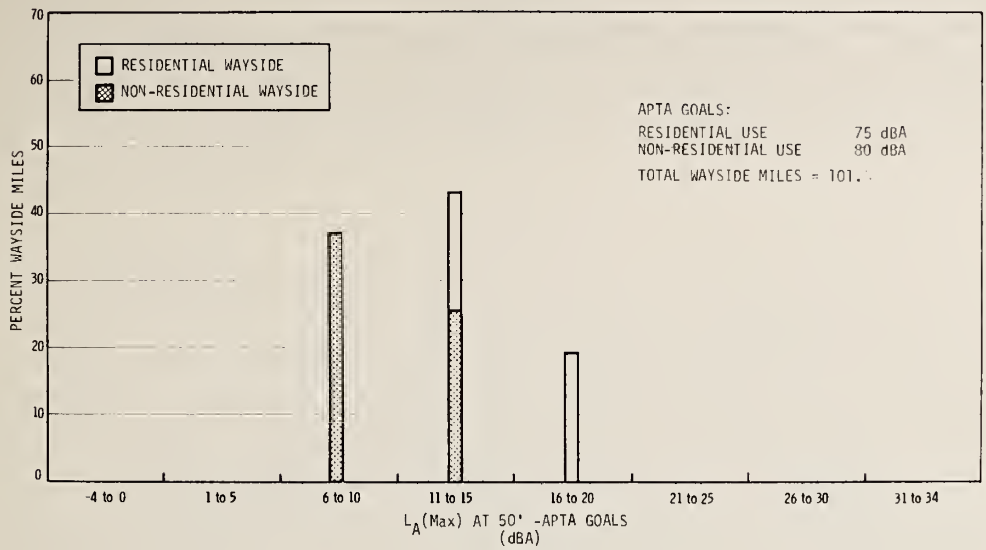



FIGURE E-17 BART SYSTEM, WAYSIDE NOISE GUIDELINE COMPARISON

# APPENDIX F - URBAN RAIL NOISE ASSESSMENT OF CTA SYSTEMS

## F.1 SYSTEM DESCRIPTION (See Table F-1)

The Chicago Transit Authority (CTA) operates on six major rapid rail routes serving all sections of the city of Chicago and several Cook County suburbs. In addition, a loop shuttle serves the Chicago central business district (see Figure F-1). The total system route length is approximately 86 miles, with 11 percent underground, 43 percent on elevated steel and 46 percent on either at-grade, open-cut, or elevated embankment track. The roadbed is primarily bolted rail on wood ties (64 percent), but welded rail on wood tie (22 percent) and welded rail on concrete ties (14 percent) are also employed.

### F.1.1 Stations

The CTA rapid rail system consists of 143 stations, 48 percent of which are situated on elevated steel structures. Stations are designated as either "A stations," "B stations," or "AB stations," with alternate trains designated as "A" or "B" trains. All trains stop at "AB stations," "A" trains stop at "A stations," etc. This allows alternate trains to progress non-stop through stations. The alternate system is not used at night nor on holidays.

The most common station configuration is the center platform (50 percent), with the side platform configuration (44 percent) also heavily represented.

### F.1.2 Transit Vehicles

The CTA rapid transit fleet comprises approximately 1100 rail vehicles, grouped into five types of vehicles. The oldest vehicles, of which there are only four (Nos. 51, 53, 54 and 75), were built in 1947-48, and are not acoustically treated. They are three-section, articulated vehicles, nearly 27.1 m (89 ft) long, with a seating capacity of 96 passengers. These vehicles are used exclusively on the Skokie Swift Service. The 4-50 series cars,

# TABLE F-1 CTA SYSTEM SUMMARY (1 OF 2)

| | NORTH-SOUTH | WEST-SOUTH | WEST-NORTHWEST | SKOKIE | EVANSTON | RAVENSWOOD | Total CTA* |
|---|---|---|---|---|---|---|---|
| A. ROUTE PHYSICAL | | | | | | | |
| 1. Length | 22.0 Miles | 20.6 Miles | 25.5 Miles | 6.2 Miles | 3.8 Miles | 10.2 Miles | 86.3 Miles |
| 2. Track type | Welded Rail with Wood Tie; Jointed Rail/ Wood Tie | Welded Rail with Wood and Concrete Ties; Jointed Rail/Wood Tie | Welded Rail with Wood and Concrete Ties; Jointed Rail/Wood Tie | Jointed Rail/ Wood Tie | Jointed Rail/ Wood Tie | Jointed Rail/ Wood Tie | |
| 3. Track Structure Mileage | | | | | | | |
| a. Underground | 4.2 | | 5.4 | | | | 9.6 |
| b. Steel El. | 13.4 | 8.6 | 6.4 | .2 | | 9.1 | 35.7 |
| c. Concrete El. | | .6 | .1 | .5 | | | 1.2 |
| d. Median Strip | | 8.9 | 8.9 | | | | 17.8 |
| e. At-Grade | | | 4.2 | 2.5 | .7 | .9 | 8.3 |
| f. In-Cut | .2 | | .3 | 1.1 | | | 1.6 |
| g. Elevated Embankment | 4.2 | 2.5 | .2 | 1.9 | 3.1 | .2 | 12.1 |
| 4. Number of Stations | 45 | 28 | 44 | 2 | 9 | 26 | 143 |
| B. VEHICLES | 6000 Series | 2000/2200 | 6000/2200/2400 | 51,53,54,75/4-50 | 6000/4-50 | 6000/4-50 | |
| 1. Year Manufactured | 1950's | 1964/1969 | 1950's/1969/1976 | 1947-48/1959-60 | 1950's/1959-60 | 1950's/1959-60 | 1947-48/1950's/1959-60/'64/'69/'76 |
| 2. Number in Service | 334 | 180/92 | 210/ 58/ 6 | 4/7 | 74/14 | 90/26 | 4 / 708 / 47 /180/150/ 6 |
| 3. Acoustical Treatment | No | Yes/Yes | No/ Yes/ Yes | No/No | No/No | No/No | No / No / No /Yes/Yes/Yes |
| C. SYSTEM SCHEDULING | | | | | | | |
| 1. Running Time | 51 Minutes | 41 Minutes | 43 Minutes (to DesPlanes) 47 Minutes (to Berwyn) | 8 Minutes | 10 minutes | 32 minutes | |
| 2. Average Running Speed | 30 mph 25 mph (Englewood Service) | 40 mph (Dan Ryan) 35 mph (Lake) 20 mph (Loop) | 40 mph (Congress) 30 mph (Elsewhere) | 40 mph | 35 mph | 30 mph 20 mph (Loop) | |

# TABLE F-1 CTA SYSTEM SUMMARY (2 OF 2)

| | NORTH-SOUTH | WEST-SOUTH | WEST-NORTHWEST | SKOKIE | EVANSTON | RAVENSWOOD | Total CTA |
|---|---|---|---|---|---|---|---|
| D. POPULATION DATA | | | | | | | |
| 1. Daily Ridership | 166,750 People/Day | 126,050 People/Day | 151,400 People/Day | 3200 | 10,400 People/Day | 69,550 People/Day | 527,350 People/Day |
| 2. Wayside Population Density | 43,210 [43,570 (Howard) 47,600 (Jackson Pk.) 29,000 (Englewood)] | 18,635 [13,695 (Dan Ryan) 21,690 (Lake)] | 27,520 [(24,325 (Congress) 31,155 (Douglas) 23,500 (Milwaukee)] | 12,470 | 15,215 | 35,190 | 30,980 People/sq. mi. |
| 3. Wayside Population within 200 ft. | 16,340 persons | 2,505 persons | 8,340 persons | 1,370 | 640 persons | 7,055 persons | 36,250 persons |
| 4. Residential Land Use (Length-% of Total wayside) | 12.6 (35.4%) | 4.5 (1.1%) | 10.1 (50.2%) | 3.7 (29.8%) | 1.4 (18.4%) | 6.7 (32.8%) | 39.0 (25.3%) |
| E. IN-CAR SOUND LEVELS | | | | | | | |
| 1. Average Inter-station $L_A$(Max) | 86.2 dBA | 86.7 dBA | 84.5 dBA | 82.5 dBA | 84.8 dBA | 87.9 dBA | |
| 2. $L_A$(Max) Standard Dev. | 4.6 dBA | 4.62 dBA | 5.31 dBA | | 1.98 dBA | 5.53 dBA | |
| 3. $L_{eq}$(R) | 84.2 dBA | 85.7 dBA | 82.1 dBA | 80.3 dBA | 82.3 dBA | 86.2 dBA | 84.2 dBA |
| F. IN-STATION SOUND LEVEL | | | | | | | |
| 1. Average Station $L_A$(Max) | 87.5 dBA | 84.5 dBA | 87.5 dBA | 76 dBA | 79.4 dBA | 84.3 dBA | 85.8 dBA |
| 1.5 Range of $L_A$(Max) | 79-103 dBA | 79-88 dBA | 76-99 dBA | | 76-80 dBA | 75-86 dBA | 75-103 dBA |
| 2. Average Station $L_{eq}$ | 76.2 dBA | 74.7 dBA | 75.3 dBA | 63.2 dBA | 71.6 dBA | 71.9 dBA | 74.5 dBA |

| G. WAYSIDE COMMUNITY SOUND LEVELS | H | E | JP | T | DR | LK | T | M | C | D | T | SKOKIE | EVANSTON | RAVENSWOOD | Total CTA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Average $L_A$(Max) @ 50' | 88.1 | 95 | 97 | 92.3 | 86.5 | 89.3 | 88.2 | 90.3 | 86 | 94.4 | 91.0 | 89.1 dBA | 84.5 dBA | 95.0 dBA | 91.5 dBA |
| 1.5 $L_A$(Max) Range @ 50' | 74-97 | | | | 76-101 | | | 82-97 | | | | 86-101 | 84-86 | 82-97 | 74-101 dBA |
| | H | E | JP | T | DR | LK | T | M | C | D | T | | | | |
| 2. Average $L_{dn}$(Trains) | 74.4 | 80 | 83.9 | 79.3 | 74.1 | 78.9 | 76.4 | 74.4 | 69.9 | 78.0 | 73.4 | 65.7 dBA | 67.3 dBA | 80.5 dBA | 75.5 dBA |
| 3. Average $L_{dn}$(Ambient) | 67.6 | 66.2 | 68.1 | 67.6 | 63.0 | 64.6 | 64.0 | 65.0 | 64.5 | 66.5 | 65.6 | 62.5 dBA | 63.6 dBA | 67.3 dBA | 66.0 dBA |
| 4. Average Relative $L_{dn}$ | 10.3 | 14.4 | 16.3 | 13.1 | 10.0 | 12.7 | 11.6 | 12.9 | 6.3 | 12.1 | 10.5 | 5.2 dBA | 5.1 dBA | 12.1 dBA | 11.1 dBA |

H = Howard Service
E = Englewood Service
JP = Jackson Park Service

DR = Dan Ryan Service
LK = Lake Service
M = Milwaukee Service

C = Congress Service
D = Douglas Service
T = Total

*The indicated values only count shared stations and trackage once (Chicago Land Use Atlas, 1970, Dept. of Development and Planning, 1974).

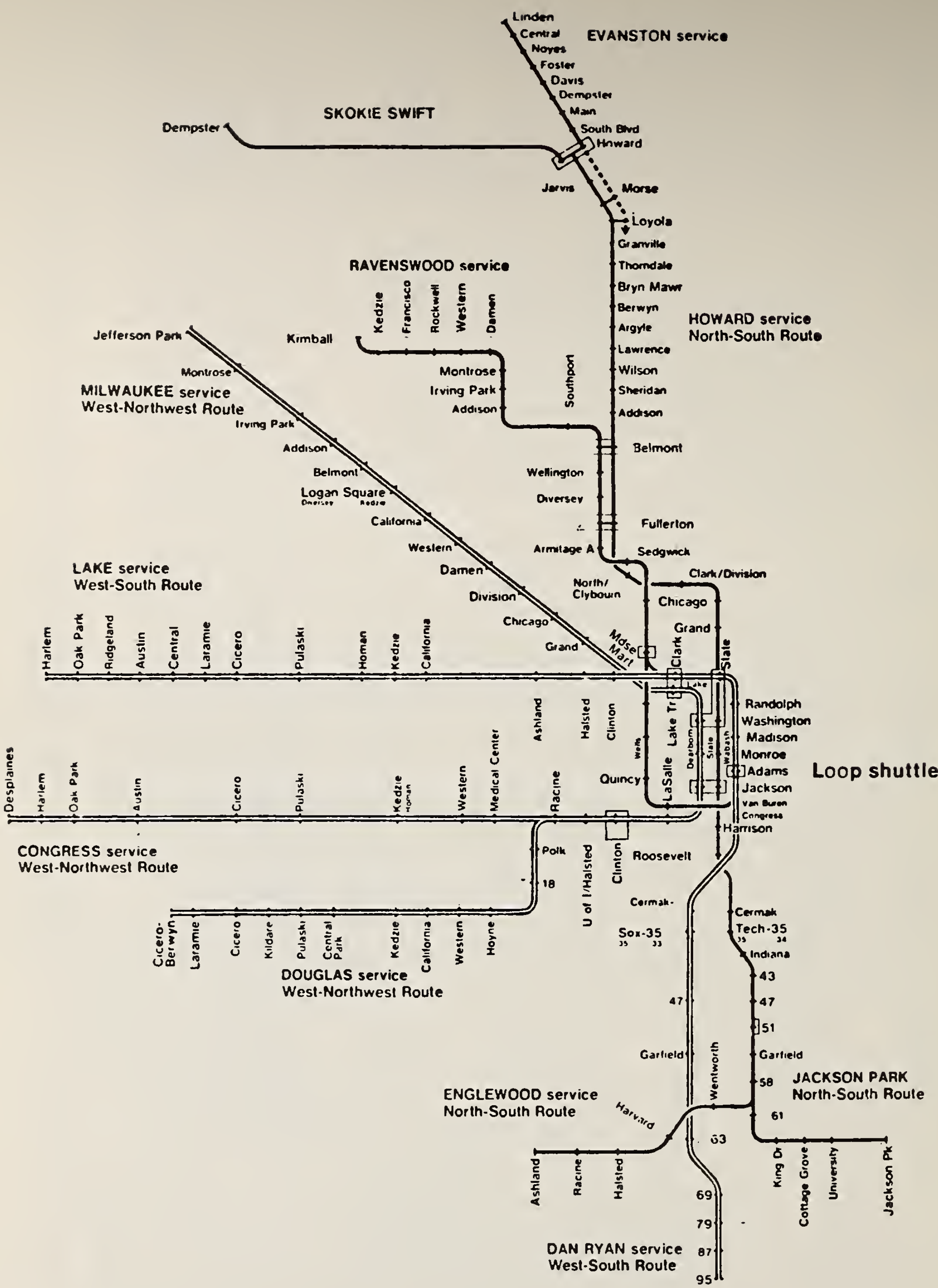



FIGURE F-1 CTA RAIL TRANSIT LINES

built in 1959-60, are not acoustically treated. They are 14.6 m (48 ft) long and seat 46 passengers. These vehicles operate on the Ravenswood, Evanston, and Skokie Swift routes and the downtown elevated loop.

The remaining three vehicle types, the 2000, 2200 and 6000 series cars, are permanently coupled in pairs ("A" and "B" units). Each of them is 14.6 m (48 feet) in length, with a seating capacity of 47 for "A" units and 51 for "B" units. Both the 2000 and the 2200 series cars are equipped with air conditioning and have sealed windows. The 6000 series vehicles, comprising approximately 65 percent of the transit fleet, were built in the 1950's. They are used on all CTA routes except the West-South and Skokie Swift, and are the only vehicles operated on the North-South route. The 6000 series cars have no acoustical treatment. The 2000 series cars, 17 percent of the fleet, were built in 1964. They operate exclusively on the West-South route. The 2200 series cars were built in 1969-70, make up 13 percent of the fleet, and operate on the West-Northwest and West-South routes.

A new vehicle, the 2400 series car, was introduced in 1976, after the noise measurements were compiled. These cars are permanently coupled in pairs ("A" and "B" units). Each one is 48 feet long, with a seating capacity of 45 for "A" units and 49 for "B" units. Presently they operate only on the West-Northwest route. The vehicles differ from the older cars in that they have a better accoustical design.

F.1.3 Route Descriptions (See Figures F-2 through F-12)

The North-South route is comprised of three services, Howard in the north, and Englewood and Jackson Park in the south. It is approximately 35 km (22 mi) long and travels on elevated embankment, 6.4 km (4.0 mi) and on elevated steel, 5.3 km (3.3 mi) from its northern terminus to the downtown area. From here it proceeds underground, 6.7 km (4.2 mi) and then travels through the South Side on elevated steel structures, 16.8 km (10.5 mi) to the two southern terminals.

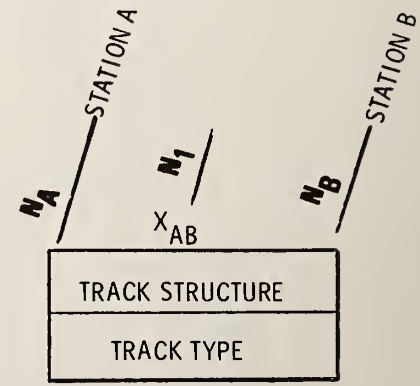
## LEGEND FOR FIGURES F-2 TO F-12

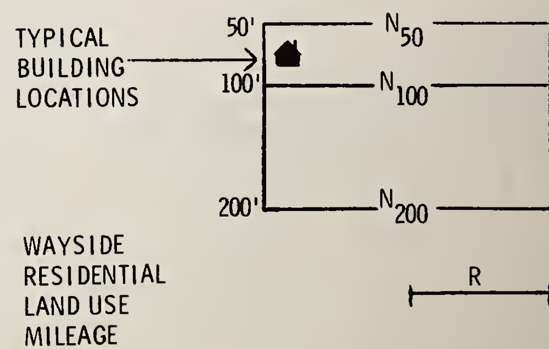
TRACK STRUCTURE

| | | |
|---|---|---|
| ES | = | ELEVATED STEEL |
| EE | = | ELEVATED EMBANKMENT |
| UG | = | UNDERGROUND |
| CV | = | CONCRETE VIADUCT |
| IC | = | IN CUT |
| AG | = | AT GRADE |
| MS | = | MEDIAN STRIP |
| EC | = | ELEVATED CONCRETE |
| A | = | AERIAL |

| | | |
|---|---|---|
| $X_{AB}$ | = | INTERSTATION DISTANCE (MILES) |
| $N_A/N_B$ | = | STATION NOISE AT STATION A/B (dBA) |
| $N_i$ | = | IN-CAR NOISE (dBA) |
| $N_{50}$ | = | WAYSIDE NOISE AT 50 FEET (dBA) |
| $N_{100}$ | = | WAYSIDE NOISE AT 100 FEET (dBA) |
| $N_{200}$ | = | WAYSIDE NOISE AT 200 FEET (dBA) |
| R | = | WAYSIDE RESIDENTIAL LAND USE MILEAGE (BOTH SIDES OF TRACK) |

DATA UNIQUE TO PARTICULAR SYSTEMS ARE NOTED ON SYSTEM SCHEMATICS



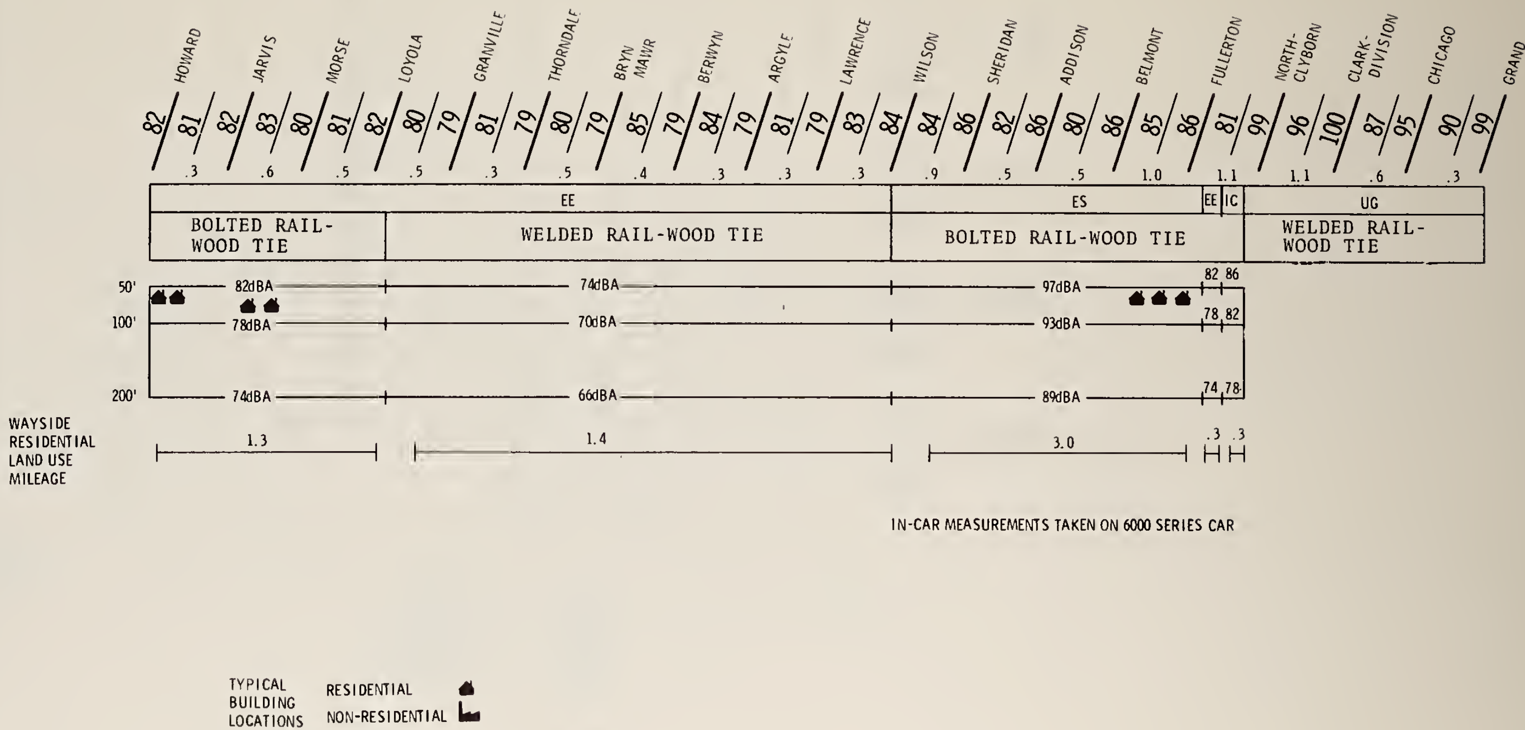



FIGURE F-2 CTA SYSTEM, NORTH-SOUTH ROUTE: HOWARD SERVICE

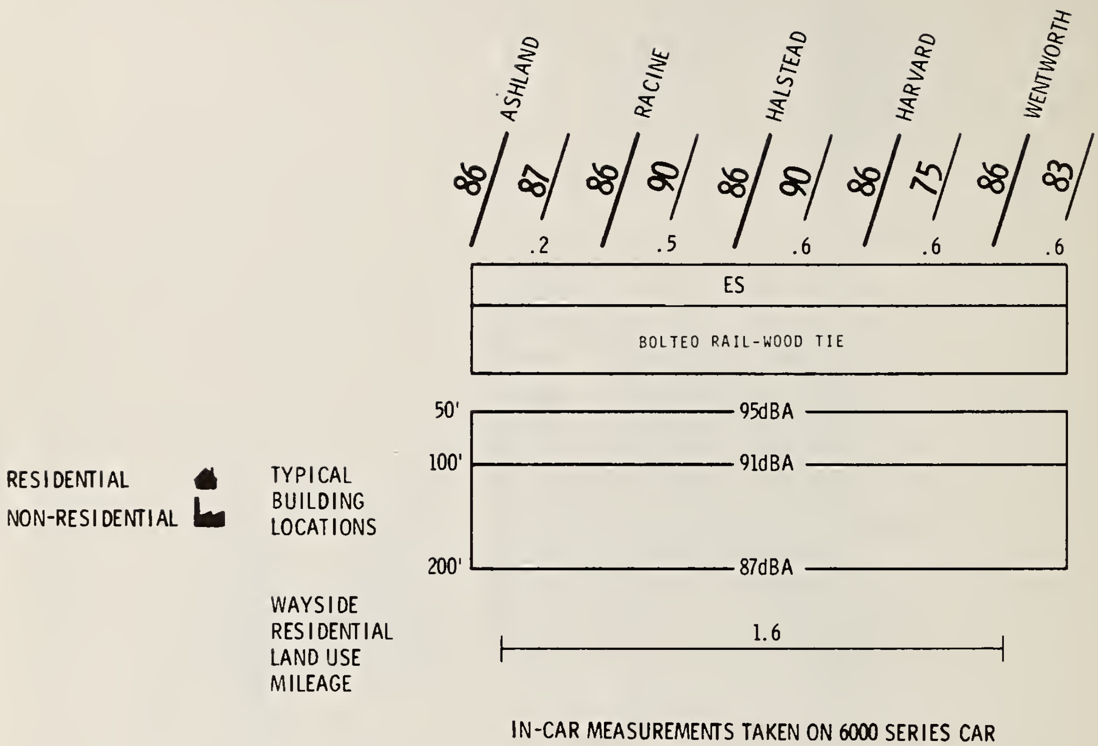



FIGURE F-3 CTA SYSTEM, NORTH-SOUTH ROUTE: ENGLEWOOD SERVICE

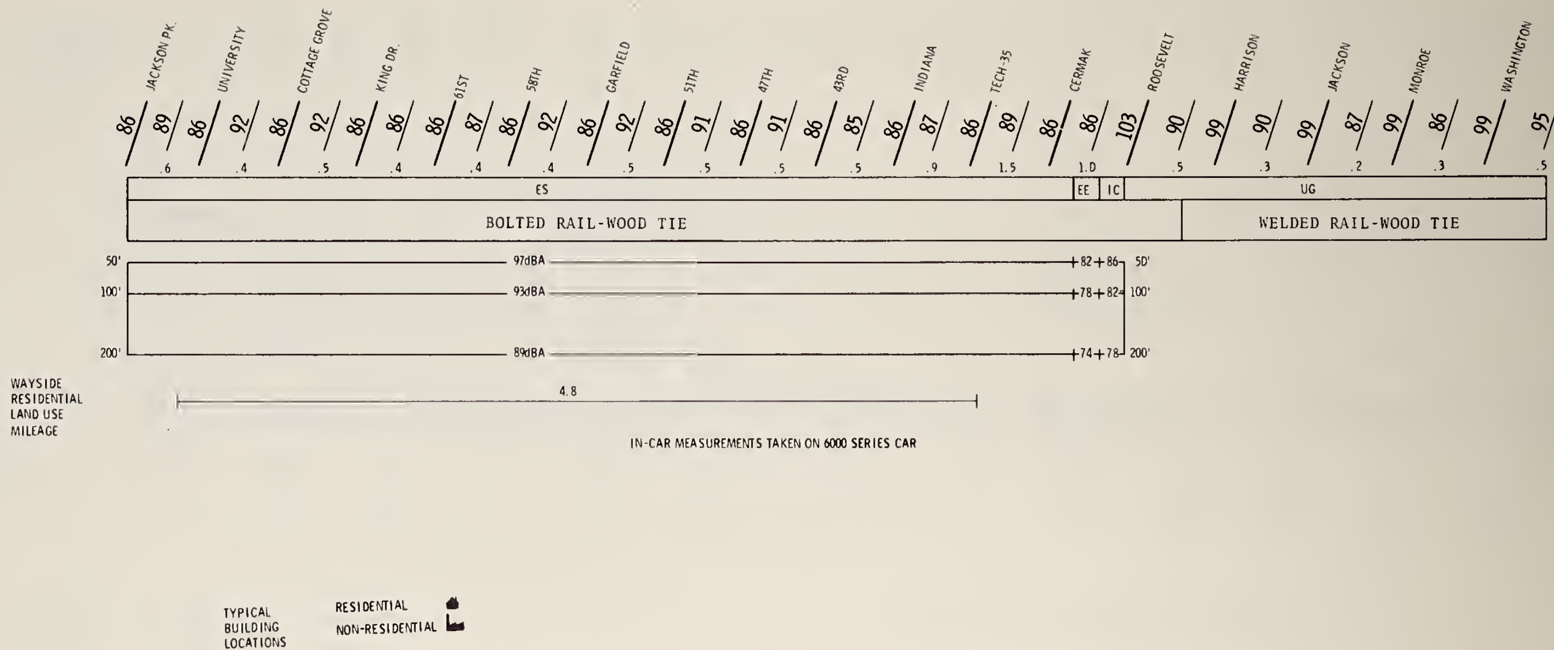



FIGURE F-4 CTA SYSTEM, NORTH-SOUTH ROUTE: JACKSON PARK SERVICE

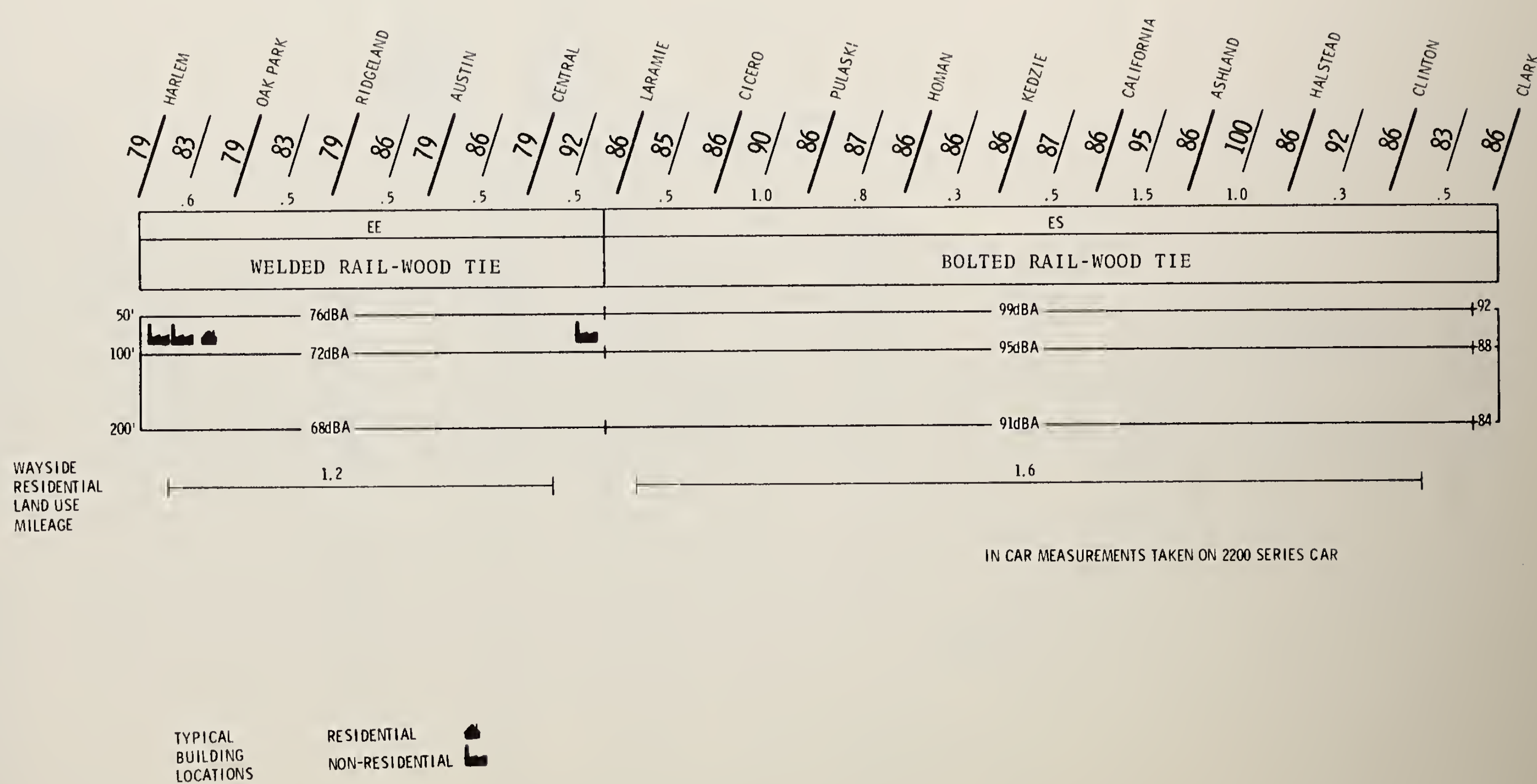



FIGURE F-5 CTA SYSTEM, WEST-SOUTH ROUTE: LAKE SERVICE

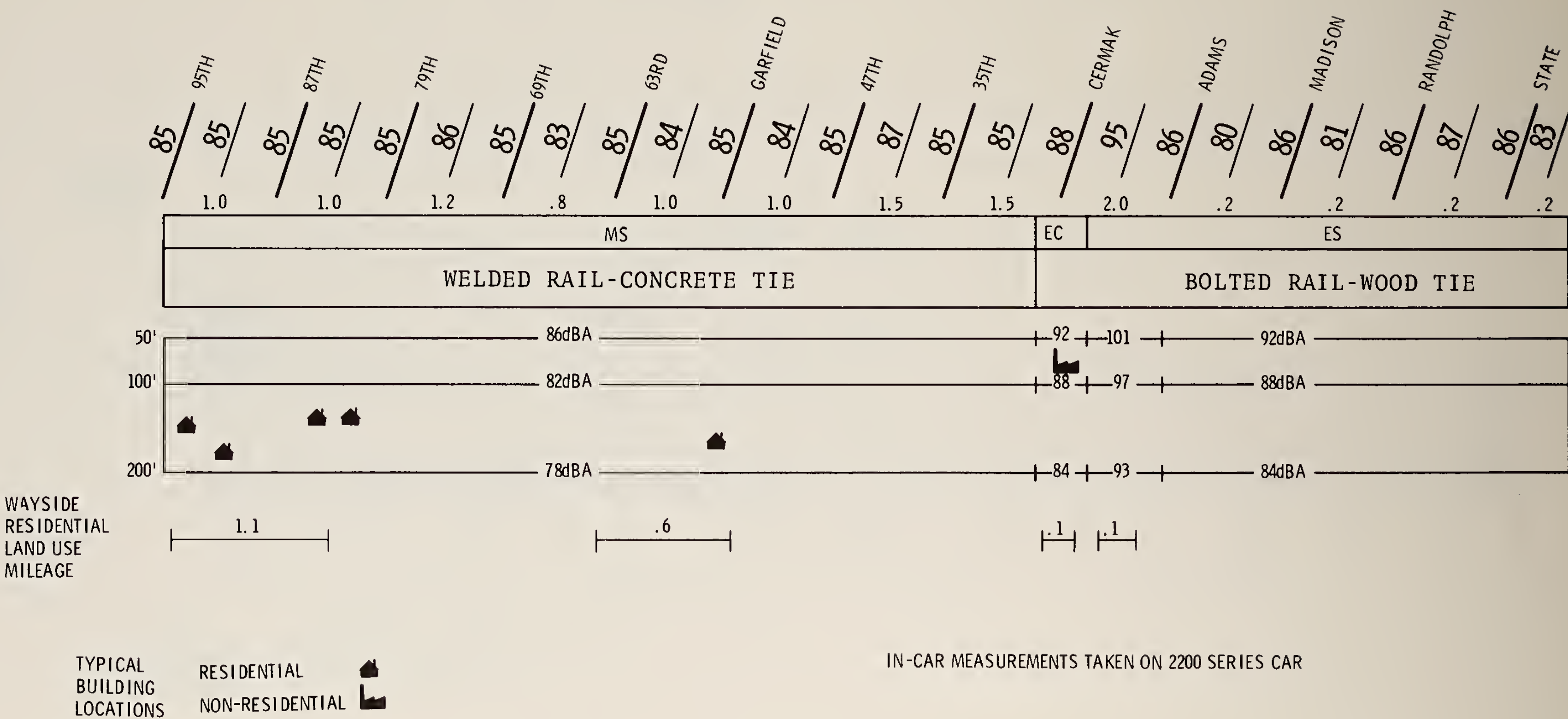



FIGURE F-6 CTA SYSTEM, WEST-SOUTH ROUTE: DAN RYAN SERVICE

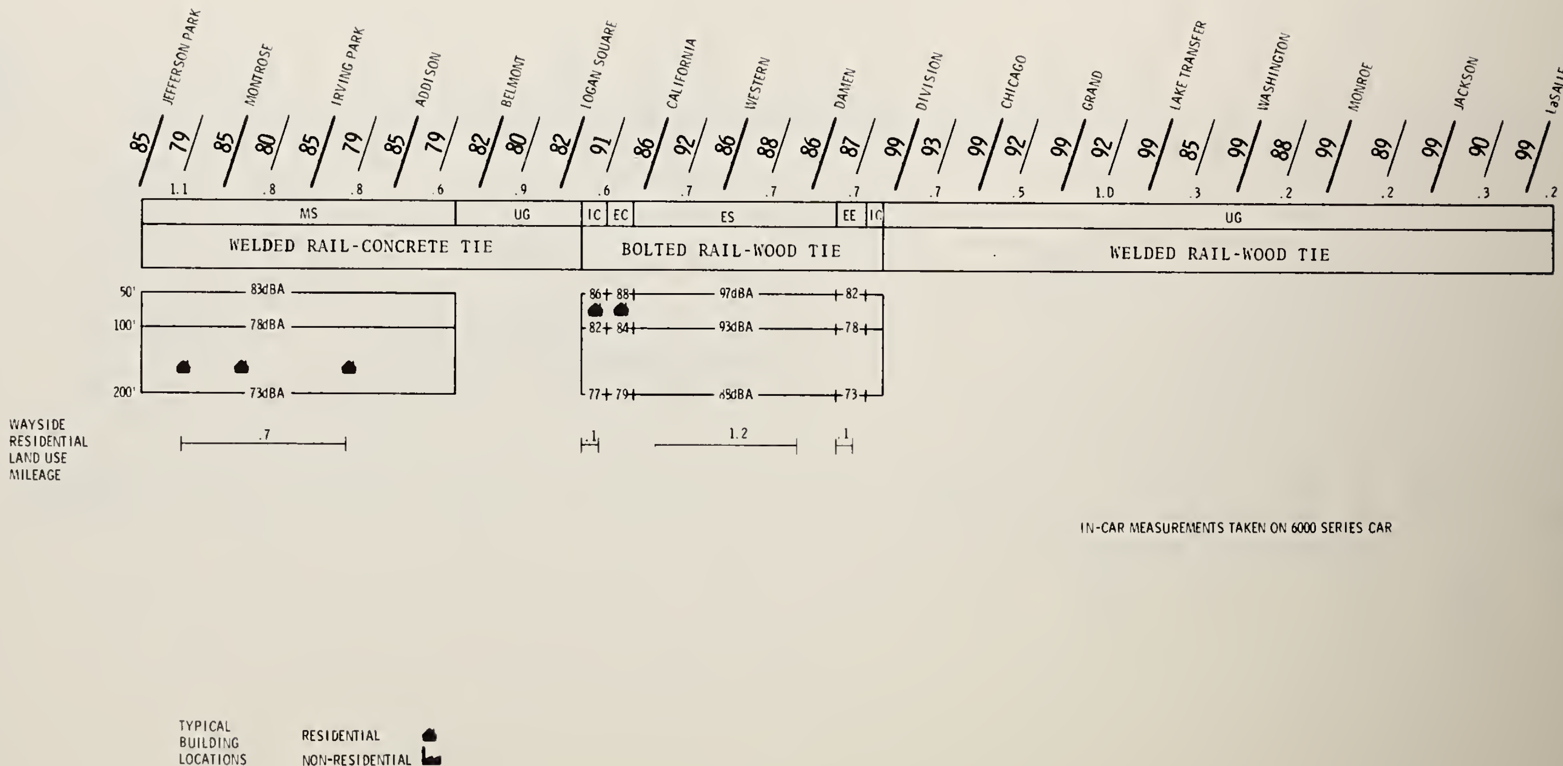



FIGURE F-7 CTA SYSTEM, WEST-NORTHWEST ROUTE: MILWAUKEE SERVICE

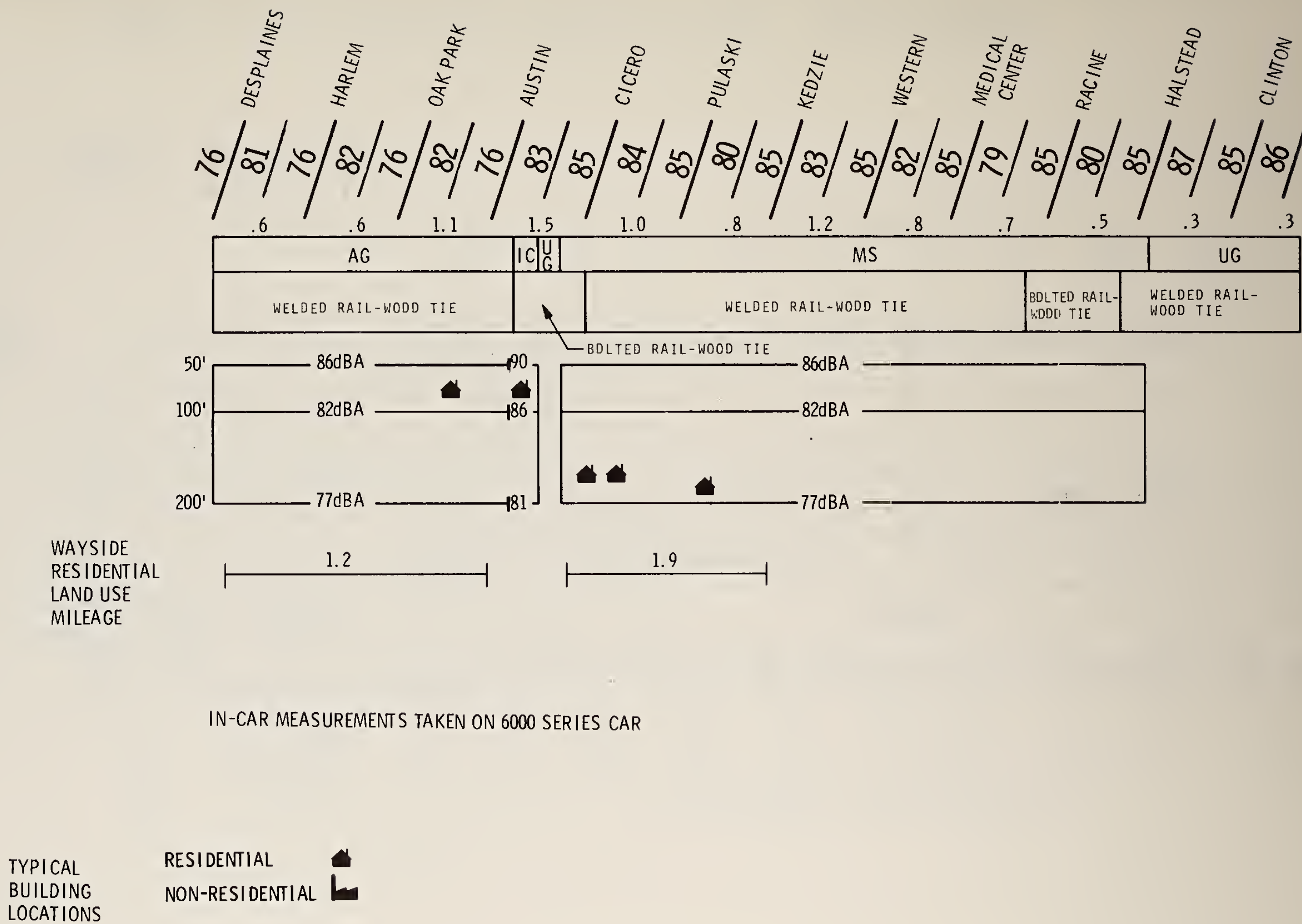



FIGURE F-8 CTA SYSTEM, WEST-NORTHWEST ROUTE: CONGRESS SERVICE

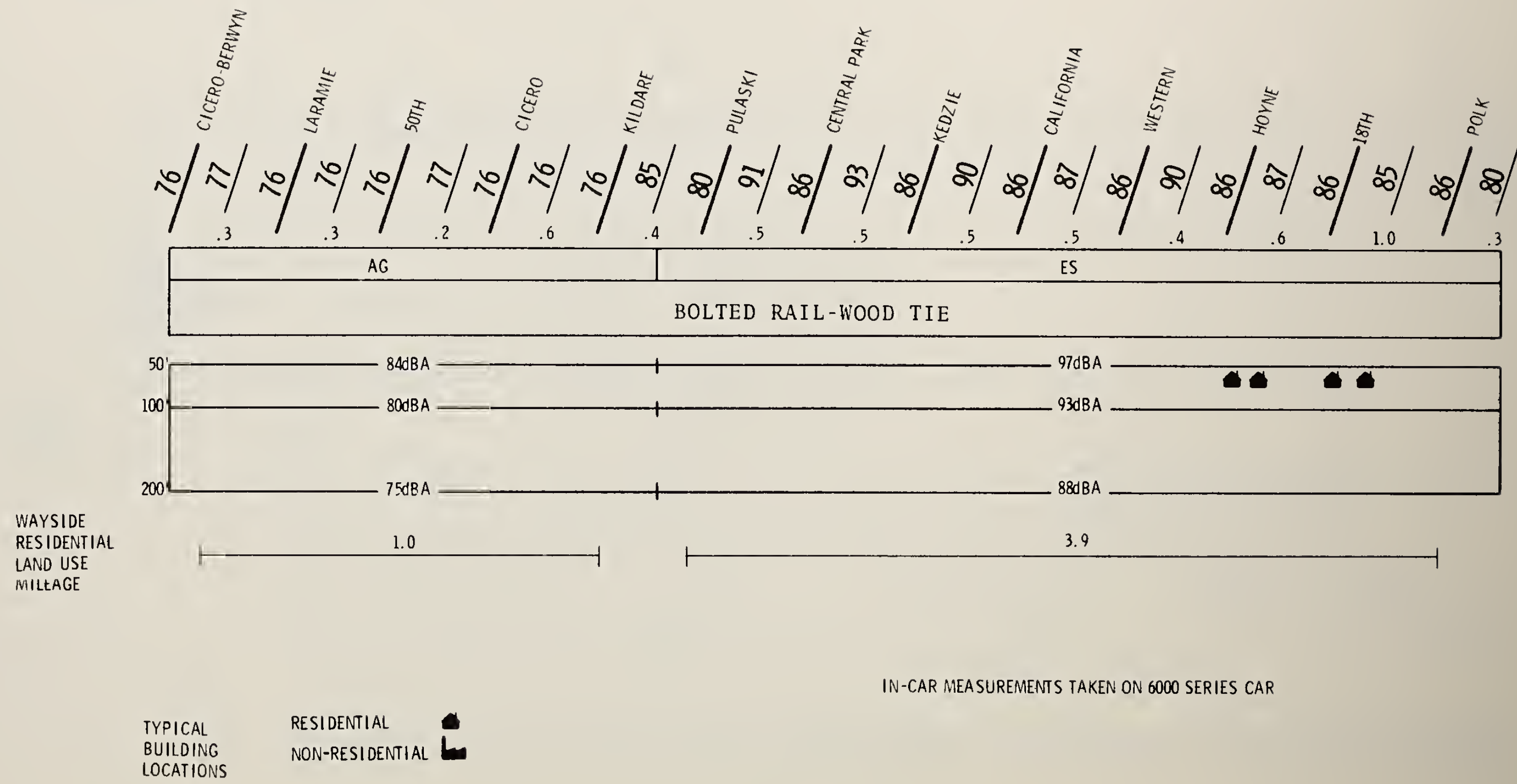



FIGURE F-9  CTA SYSTEM, WEST-NORTHWEST ROUTE:  DOUGLAS SERVICE

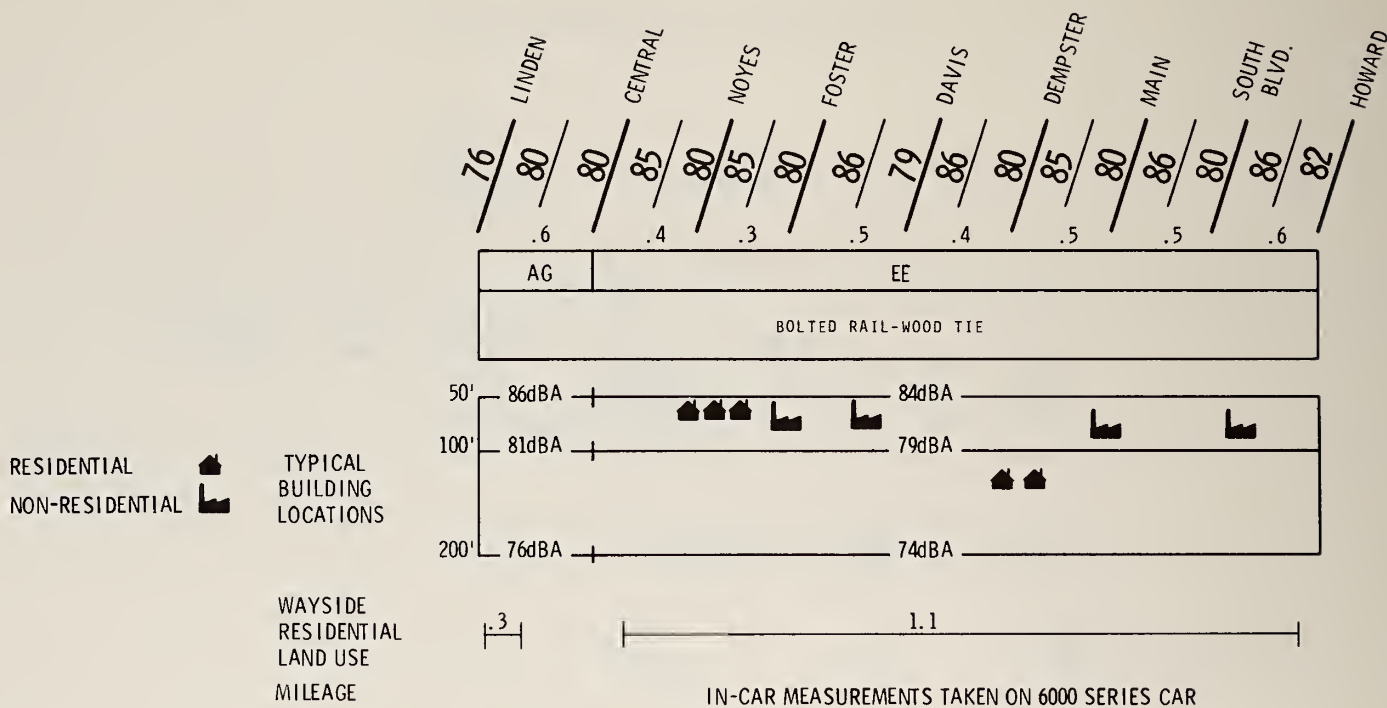



FIGURE F-10 CTA SYSTEM, EVANSTON SERVICE

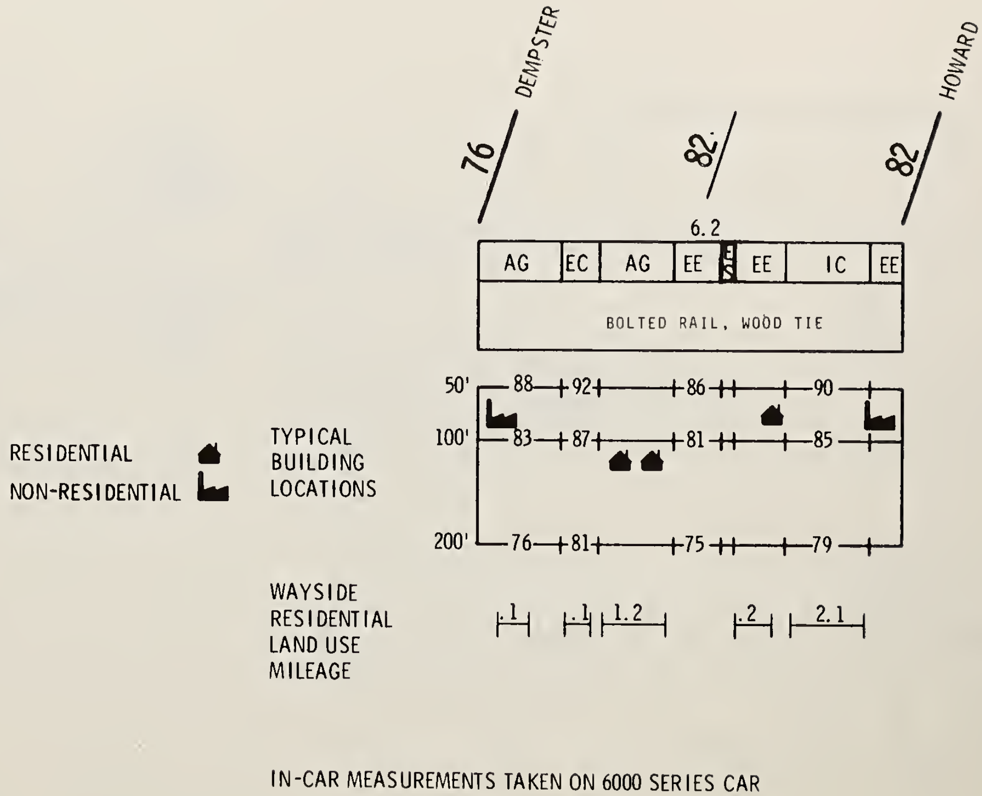



FIGURE F-11 CTA SYSTEM, SKOKIE SWIFT

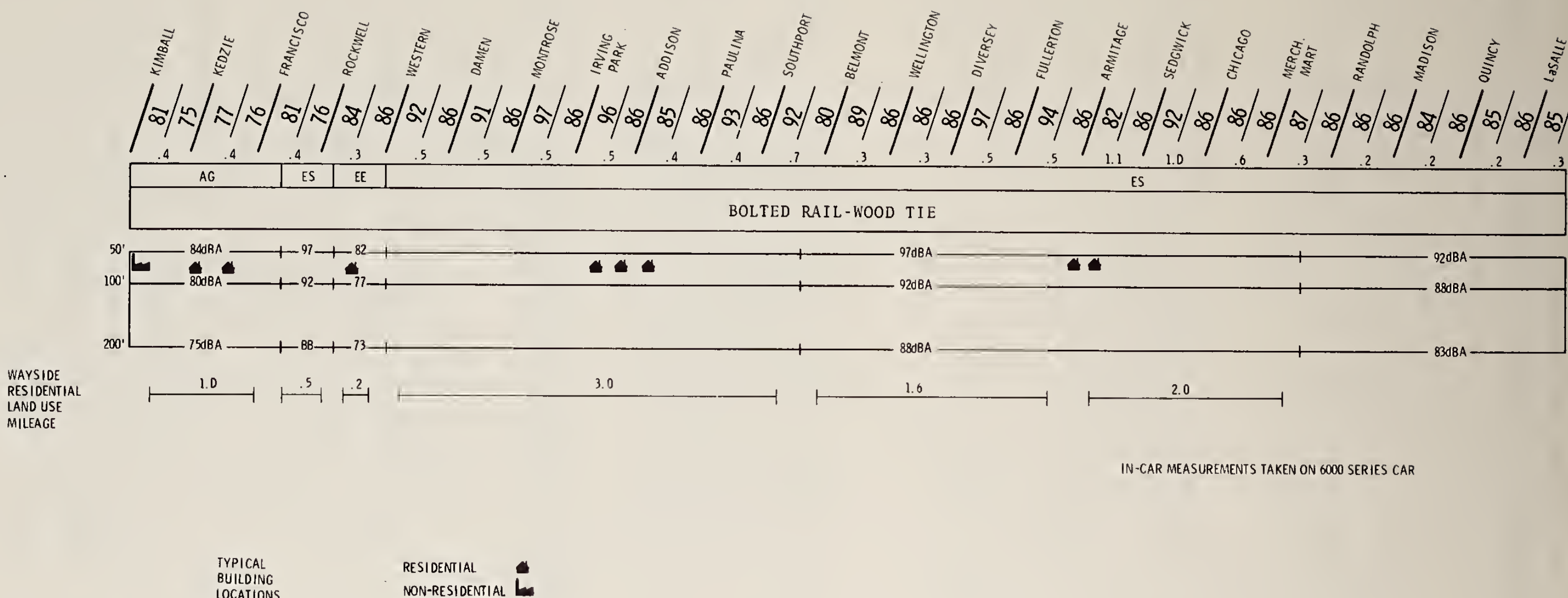



FIGURE F-12 CTA SYSTEM, RAVENWOOD SERVICE

Headways vary from 15 minutes in the early morning hours to three minutes during the peak periods. Train lengths also fluctuate between two and eight cars per train throughout the day.

Running time from the northern terminus to each of the southern terminals is 51 minutes, and the average operating speed is 48 km/h (30 mph) for the route, except on the branch to the southwest terminus, where the average operating speed decreases to 40 km/h (25 mph).

The Lake and Dan Ryan Services make up the West-South route, which is nearly 34 km (21 mi) long. Proceeding from the western terminal on elevated embankment track 4 km (2.5 mi) through the suburbs of River Forest and Oak Park, it continues on elevated steel structure 13.8 km (8.6 mi) through western Chicago, around the downtown loop, and travels the final leg down the median strip of the Dan Ryan Expressway 14.4 km/h (9.0 mi) to its southern terminal.

End-to-end running time is 41 minutes for the route, with average operating speeds of 56 km/h (35 mph) for the western portion, 32 km/h (20 mph) around the downtown loop, and 64 km/h (40 mph) for the southern sections. Headways vary from 30 minutes between 1:15 A.M. and 4:45 A.M. to five minutes during the peak hours.

The Milwaukee, Congress, and Douglas Services traverse the west and northwest portions of the city as well as the suburbs of Oak Park, Forest Park, Cicero, and Berwyn, and comprise the West-Northwest route. Proceeding from its northwestern terminal in Jefferson Park, down the median of the Kennedy Expressway 50 km (3.1 mi), the route continues in a southeasterly direction via a short section of underground, 1.9 km (1.2 mi), and elevated steel, 3.0 km (1.9 mi), track. It traverses the center of the city in an underground section, 6.7 km, (4.2 mi) and travels to the Des Plaines terminus via the median of the Congress Expressway, 9.3 km (5.8 mi), and over at-grade track, 4.5 km (2.8 mi). It reaches the second western terminal in Berwyn via a section of elevated steel, 7.2 km (4.5 mi), and at grade, 2.2 km (1.4 mi), track.

Trip time from the northwestern terminal, Jefferson Park, to the Des Plaines terminus is 43 minutes; to the Berwyn terminus, 47 minutes. The average operating speed from the downtown subway portal to the Des Plaines terminal is 60 km/h (40 mph); the other route sections show an operating speed of 48 km/h (30 mph). Headways vary from 30 minutes in the early morning hours to five minutes during peak periods. Train lengths also vary from two to six cars per train.

The Evanston and Skokie Swift routes provide service to the suburbs of Evanston, Wilmette, Skokie, and Morton Grove, and are approximately four and six miles long, respectively. The Evanston trackage is at-grade (20 percent) and elevated embankment (80 percent), whereas the Skokie track is primarily at-grade (40 percent), elevated embankment (30 percent), and open-cut (16 percent). The remaining mileage on the Skokie route is located on either elevated concrete or elevated steel track.

The basic journey of the Evanston route is from its Linden terminal to the northern terminal at the North-South Line (Howard Street). In addition, trains which operate during the morning and evening peak periods travel from the Linden terminal to the downtown loop and back again. Headways vary from 30 minutes between 3:00 A.M. and 4:00 A.M. to four minutes during the peak hours, with train lengths ranging from one to six cars per train. The average operating speed is 56 km/h (35 mph), and the running time from Linden to Howard is ten minutes.

The Skokie Swift Service operates either one-car trains or three-unit articulated vehicles. Headways range from 30 minutes to seven minutes, and the average operating speed is 64 km/h (40 mph). Running time from Dempster to Howard is eight minutes.

The Ravenswood Line is approximately 16 km (10 mi) in length, and except for a short at-grade section, 1.4 km (0.9 mi) at its terminal, it runs almost entirely on elevated steel track. The average operating speed for most of the route is 48 km/h (30 mph), with speeds reduced to 32 km/h (20 mph) in the downtown loop section. Headways vary from 40 minutes to four minutes and either two- or six-car trains are employed.

Running time between Kimball and LaSalle Stations is approximately 32 minutes.

## F.2 IN-CAR NOISE

### F.2.1 $L_A$(Max)

In-car $L_A$(Max) levels for the CTA are extremely diverse, ranging from 75 to 100 dBA. Unlike the other transit systems studied, where noise levels were measured for all car types used on each line, only the noisiest car type for each line was documented for the CTA. Thus, on the Congress and Douglas Services only the in-car noise levels for the older 6000 series cars are analyzed, even though acoustically treated 2000 or 2200 cars are also operated.

The differences in average in-car $L_A$(Max) for each line shown in Table F-2 are largely reflective of differences in type of track structure on the routes. A positive relationship is also evident between in-car noise levels and train speed, which was documented in detail in the CTA contractor's report.

When making comparisons between newer cars which have been acoustically treated and the older 6000 series, which have not, one finds there is no evidence that car type makes a difference in the in-car noise level (Table F-2). Average running speeds are generally higher on the lines on which acoustically treated cars are operated. If the increase in sound levels expected from higher train speeds is accounted for, the two car types have approximately equal in-car $L_A$(Max) levels. A possible explanation for this is offsetting differences in wheel/rail conditions.

TABLE F-2 IN-CAR NOISE SUMMARY

| | UNDERGROUND | ELEVATED STEEL | AT-GRADE (Jointed) | AT-GRADE (Welded) | IN-CUT | EMBANKMENT |
|---|---|---|---|---|---|---|
| 6000 Series Cars | 90 dBA | 88 dBA | 80 dBA | 82 dBA | 84 dBA | 84 dBA |
| 2200 Series Cars | | 91 dBA | | 85 dBA | | 85 dBA |

Figures F-13A and F-13B, therefore, are largely reflective of track structure differences between the CTA routes. Average $L_A$(Max) levels by track structure are given in Table F-2. From lowest to highest average $L_A$(Max) level, for all types of cars considered, the types of track rank as follows: at-grade (jointed rail), at-grade (welded), in-cut, embankment, elevated steel, and underground (contractor's data suggest that noise levels on at-grade welded track may be higher than on at-grade jointed track because of higher speeds during the noise measurements).

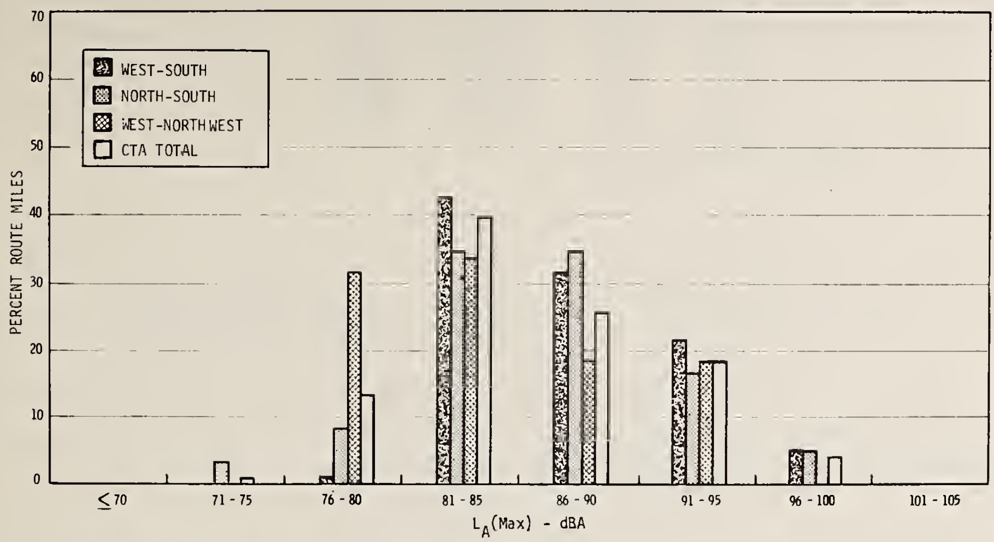



FIGURE F-13A CTA SYSTEM, DISTRIBUTION OF IN-CAR PLATEAU NOISE LEVELS

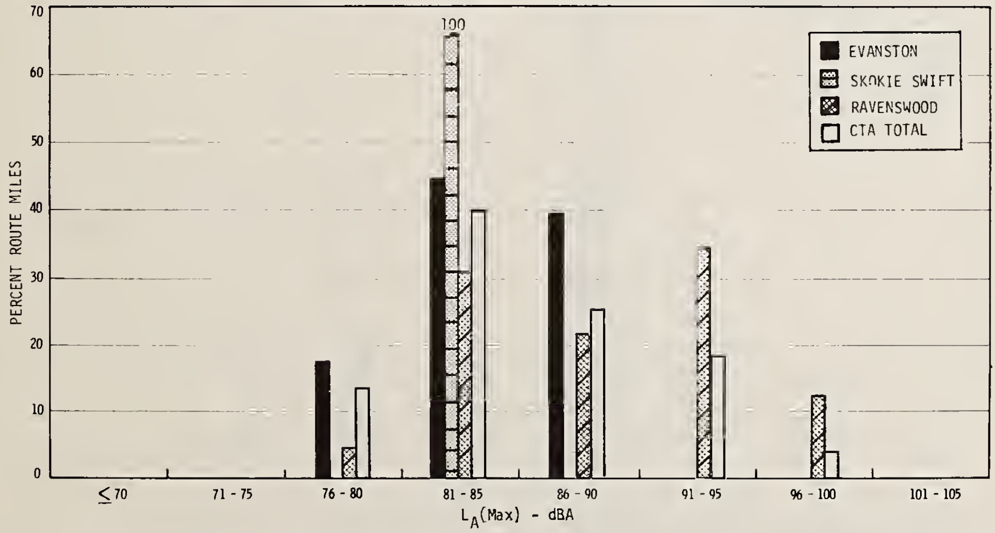



FIGURE F-13B CTA SYSTEM, DISTRIBUTION OF IN-CAR PLATEAU NOISE LEVELS

### F.2.2 In-Car Equivalent Noise Levels

Route equivalent noise levels, $L_{eq}(R)$, characterizing the in-car noise environment for complete end-to-end trips on each of the CTA routes are as follows: Skokie, 80.3 dBA; Evanston, 82.3 dBA; West-Northwest, 82.1 dBA; North-South 84.2 dBA; Ravenswood, 86.2 dBA; and West-South, 85.7 dBA (2200 series cars).

The distribution of route miles versus inter-station $L_{eq}$, Figures F-14A and F-14B, is similar to the $L_A$(Max) distribution from which it was derived. Again, a positive correlation is evident between type of track structure and in-car $L_{eq}$. Sixty-nine percent of the total CTA route mileage has in-car $L_{eq}$ levels of less than 86 dBA.

### F.2.3 In-Car Noise Exposure

Figure F-15 represents an estimate of ridership exposure to in-car noise on the entire CTA system. Using methods and assumptions discussed in Appendix H, patronage was weighted by estimated trip times, and the result, people-hours, was distributed over the inter-station $L_{eq}$ levels. Using this method, one can estimate that 69 percent of the CTA ridership is exposed to in-car noise environments characterized by $L_{eq}$ of less than 86 dBA.

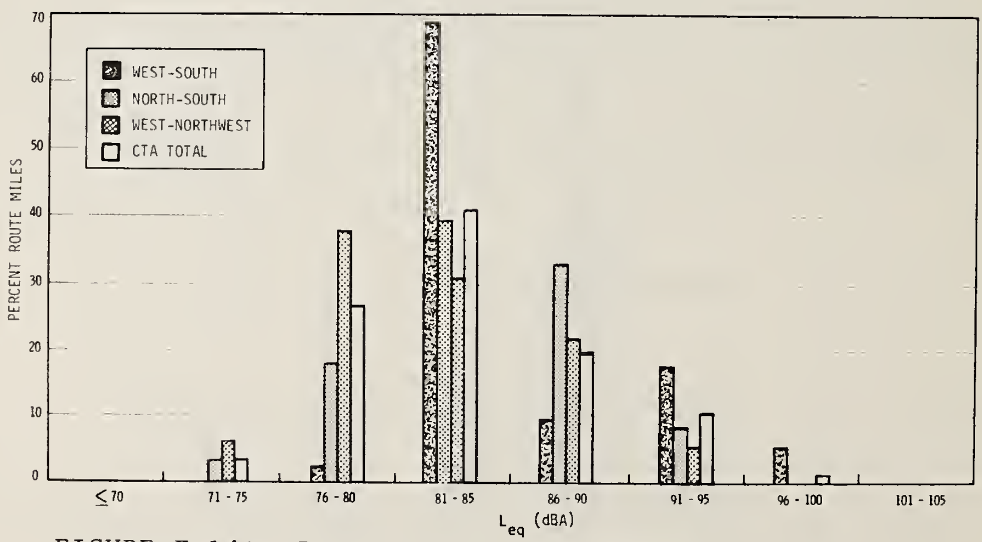



FIGURE F-14A CTA SYSTEM, DISTRIBUTION OF IN-CAR EQUIVALENT SOUND LEVELS

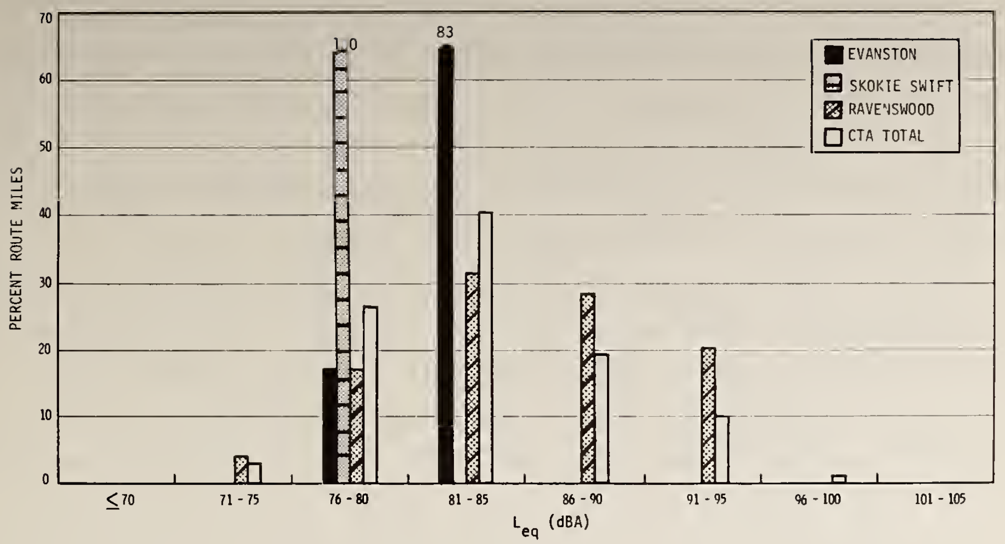



FIGURE F-14B CTA SYSTEM, DISTRIBUTION OF IN-CAR EQUIVALENT SOUND LEVELS

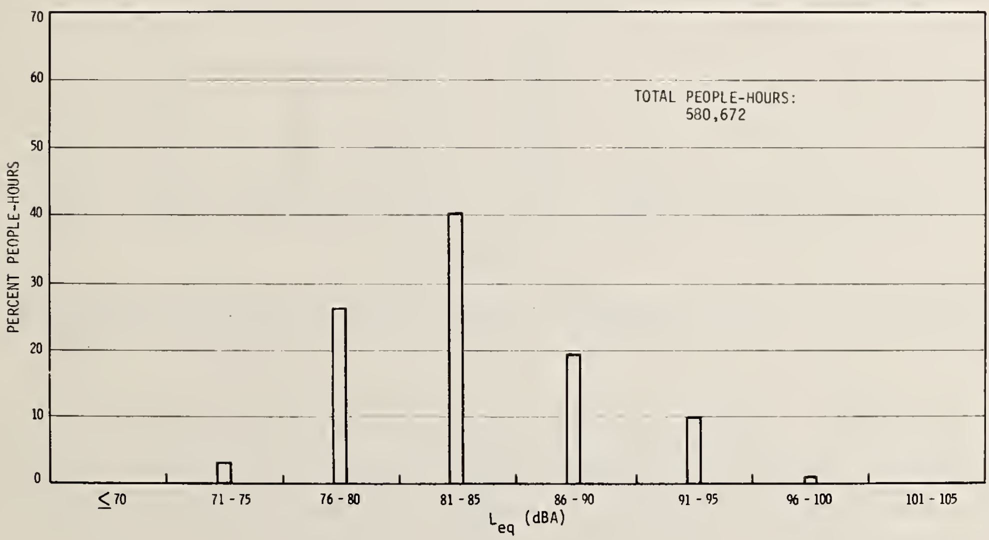



FIGURE F-15 CTA SYSTEM, IN-CAR NOISE EXPOSURE

F.2.4 Comparison of CTA In-Car $L_A$(Max) with APTA Guidelines

Figure F-16 shows the distribution of mileage over the CTA in-car $L_A$(Max) levels relative to the APTA goals. Ninety-nine percent of the mileage is characterized by $L_A$(Max) above the APTA goal for that type of track. The only segment which meets the APTA goal is a small section of underground track 1.4 km (0.9 mi), and even here the in-car $L_A$(Max) is 80 dBA.

Ninety-three percent of the route mileage has in-car $L_A$(Max) of more than five dBA above the APTA goals. In-car $L_A$(Max) on elevated steel track deviates furthest from the APTA goal, by 21 to 30 dBA. Sections of welded track on embankments are 21 to 25 dBA above the goals, but this may be attributed to the low APTA

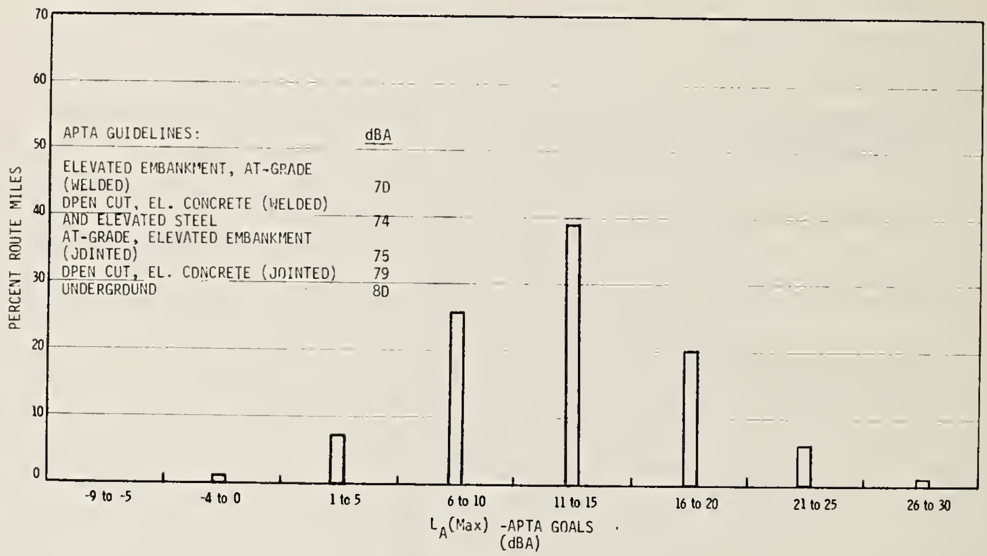



FIGURE F-16 CTA SYSTEM, IN-CAR NOISE GUIDELINE COMPARISON

goal of 70 dBA. Ranging from most to least deviation from the APTA goals are the following types of track structure: elevated steel, embankment (welded), at-grade (welded), underground, embankment (jointed), in-cut, and at-grade (jointed).

## F.3 STATION NOISE

### F.3.1 $L_A$(Max) and $L_{eq}$ (Figures F-17, F-18)

Station $L_A$(Max) levels for CTA stations are strongly related to the type of track structure. In this analysis, therefore, $L_A$(Max) values for stations in which noise measurements were not taken have been extrapolated from measured values, based on type of track structure. Station types from highest to lowest $L_A$(Max) are underground (97 dBA), elevated concrete, elevated steel (86 dBA), and embankment (80 dBA), at-grade (76 dBA). The majority of the average station $L_A$(Max) levels are in the 86 to 90 dBA range, representing the stations on elevated track. Underground stations are characterized by $L_A$(Max) levels of 96 to 100 dBA, with the Roosevelt Station at 103 dBA. The $L_A$(Max) for stations at-grade or on embankments falls mostly in the 76 to 80 dBA range, and those in the median strip are in the 81 to 85 dBA interval. No consistent relationship is evident between station noise levels and car type or train length. (The contractor noted one exception, however: In underground stations, two-car trains have lower noise levels than four- or eight-car trains.)

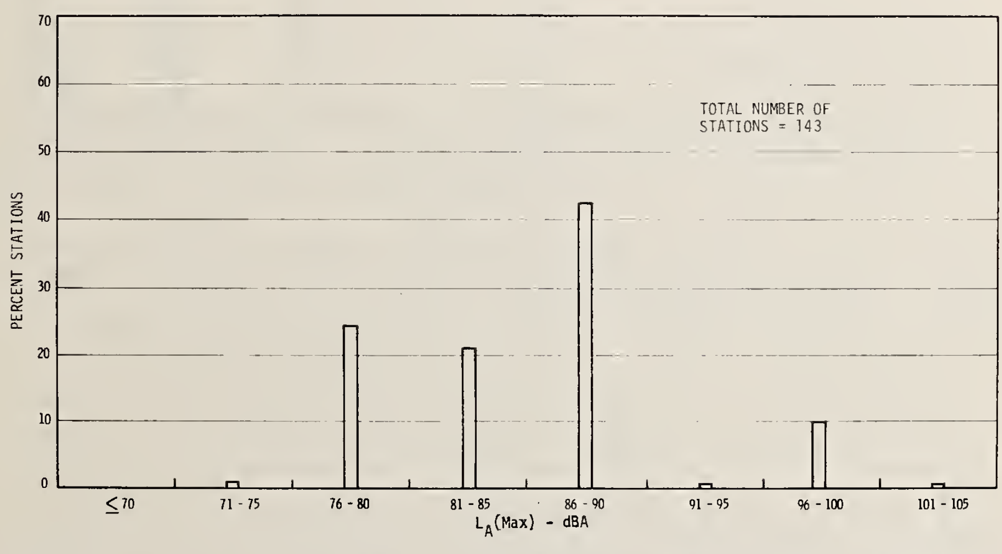



FIGURE F-17 CTA SYSTEM, IN-STATION MAXIMUM NOISE LEVELS

As shown in Figure F-18, $L_{eq}$ values for the majority of the CTA stations are in the 71 to 75 dBA range. The $L_{eq}$ distribution is strongly related to type of track structure in the stations, with some variation due to differences in headways on the lines. Underground stations account for 12 percent of the stations characterized by station $L_{eq}$ values greater than 85 dBA.

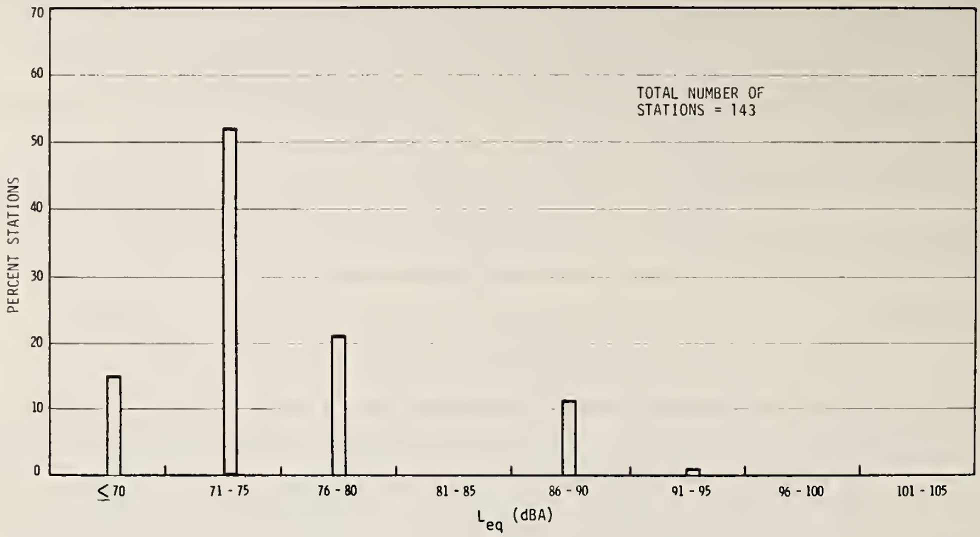



FIGURE F-18 CTA SYSTEM, IN-STATION EQUIVALENT SOUND LEVELS

## F.3.2 Station Exposure

The distribution of patronage by station $L_{eq}$ is shown in Figures F-19A and F-19B. The distribution is similar to the one in Figure F-18, except that the underground stations at 86 to 90 dBA account for a proportionately greater share of the system patronage. The patronage exposed to levels less than 71 dBA is mostly those using the West-Northwest and West-South routes.

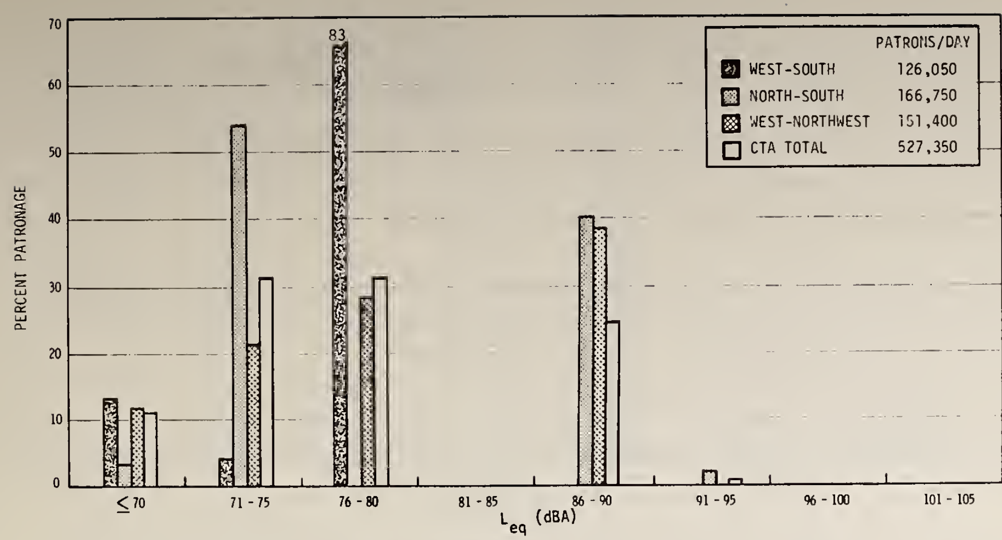



FIGURE F-19A CTA SYSTEM, IN-STATION NOISE EXPOSURE

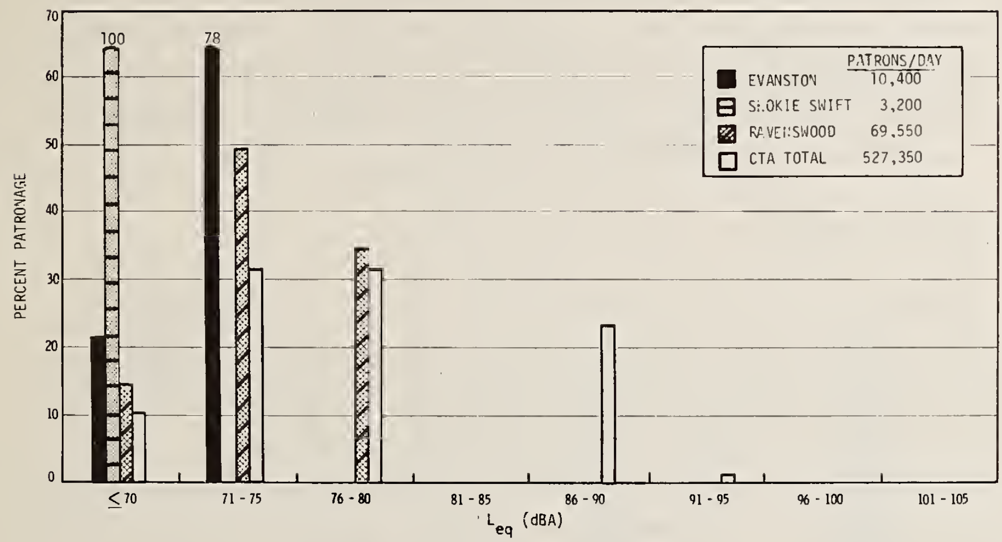



FIGURE F-19B CTA SYSTEM, IN-STATION NOISE EXPOSURE

### F.3.3 Comparison of CTA Station $L_A$(Max) with APTA Guidelines

Figure F-20 compares CTA station $L_A$(Max) levels with the APTA goals for station noise. Thirteen percent of all stations, all of which are at-grade, are below the APTA goal. All of the aboveground stations are within ten dBA of the goals. Conversely,

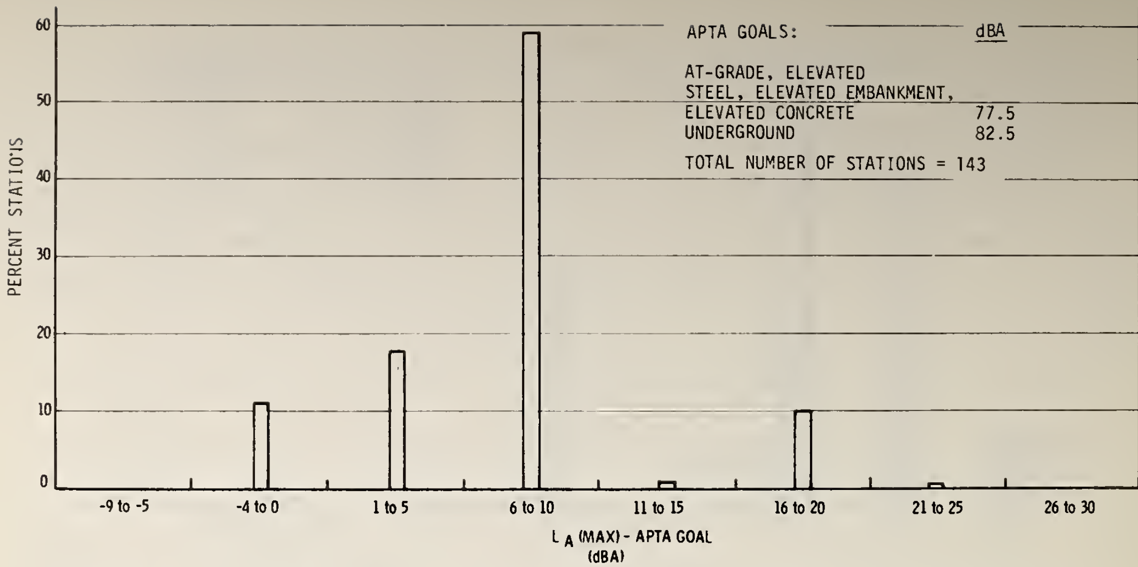



FIGURE F-20 CTA SYSTEM, IN-STATION NOISE GUIDELINE COMPARISON

nearly 85 percent of the underground stations are at least 11 dBA higher than the APTA goals, with the majority 16 to 25 dBA higher. The concentration in the six to ten dBA range reflects the number of elevated steel stations, 97 percent of which are represented in this interval.

## F.4 CTA WAYSIDE NOISE

### F.4.1 $L_A$(Max),

The average A-weighted maximum pass-by levels, $L_A$(Max), at 15 m (50 ft) from the near track center-line range from 74 to 101 dBA, for the total CTA rapid transit system. The method used to determine these levels was as follows. Wayside measurements were taken at selected sites adjacent to various types of track on the different routes. The wayside noise data for the CTA was unique in that accurate speed data was recorded for the pass-bys for which wayside noise measurements were taken. Given this information, the levels were normalized to 15 m (50 ft) at 48 km/h (30 mph) using a relationship between speed and $L_A$(Max).* By employing the same relationship, pass-by levels were established and assigned to

*R. Lotz, "Railroad and Rail Transit Noise Sources," Journal of Sound and Vibration, Vol. 51, No. 3, p. 326.

relationship, pass-by levels were established and assigned to the the various sections of the overall system according to the average operating speed on each section. The average operating speed varied from 32 km/h (20 mph) on the elevated steel portion of the downtown loop to nearly 64 km/h (40 mph) on the Skokie Swift Service.

The CTA system has been disaggregated into six routes. Figures F-21A and F-21B show the percentage of residential miles against $L_A$(Max) at 15 m (50 ft). More than half (51 percent) of the mileage is adjacent to elevated steel track exhibiting the highest $L_A$(Max) levels (96 to 101 dBA), whereas the lowest levels (74 and 76 dBA) are recorded adjacent to welded, elevated embankment track.

For the intermediate $L_A$(Max) values, both type of track and operating speed contribute to the difference in $L_A$(Max) levels. For example, levels of 81 to 85 dBA were recorded adjacent to elevated embankment, at-grade, and median strip track, where the average operating speed of the trains was between 48 and 56 km/h (30 and 35 mph). $L_A$(Max) values of 86 to 90 dBA were recorded over similar track when the average speed was 64 km/h (40 mph).

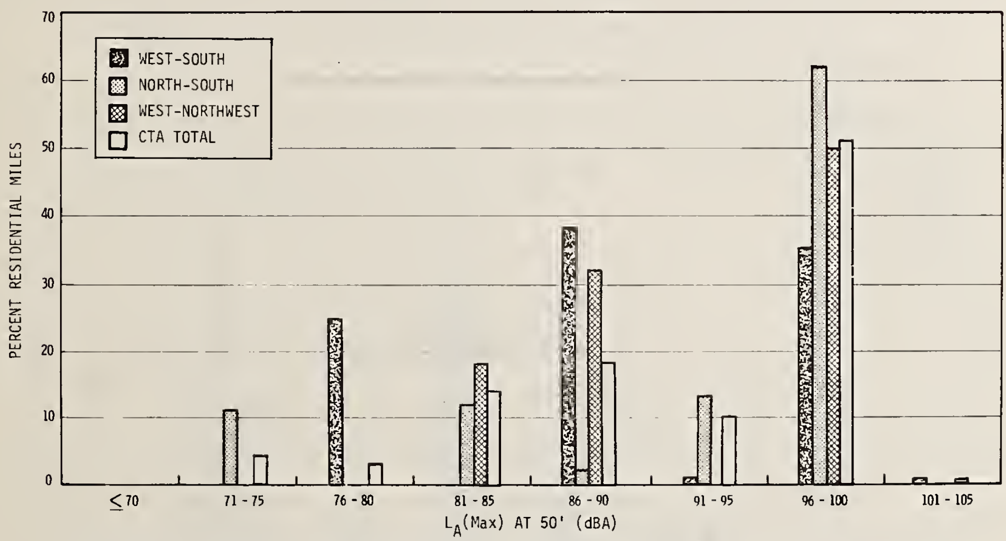



FIGURE F-21A CTA SYSTEM, DISTRIBUTION OF RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

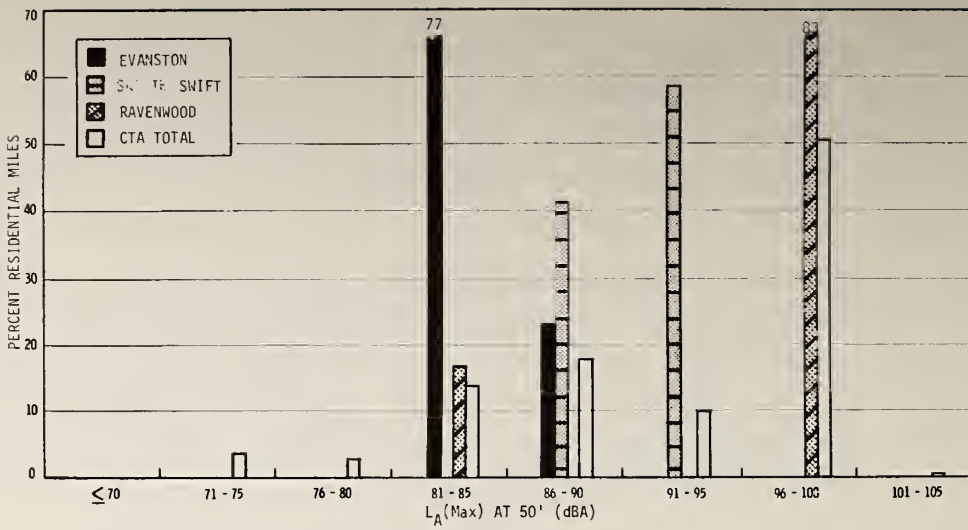



FIGURE F-21B CTA SYSTEM, DISTRIBUTION OF RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

The same pattern holds for the non-residential mileages illustrated in Figures F-22A and F-22B. Thirty-six percent of the mileage is adjacent to elevated steel track, where the highest $L_A$(Max) levels are observed, and six percent abuts welded, elevated embankment trackage. Most of the remaining mileage (34 percent) is exposed to levels of 86 to 90 dBA adjacent to a variety of track structures.

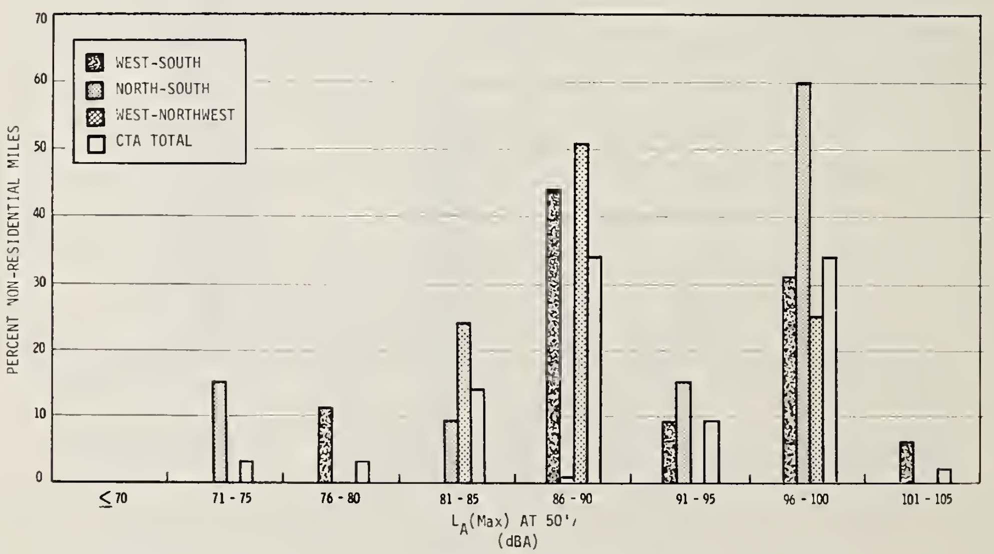



FIGURE F-22A CTA SYSTEM, DISTRIBUTION OF NON-RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

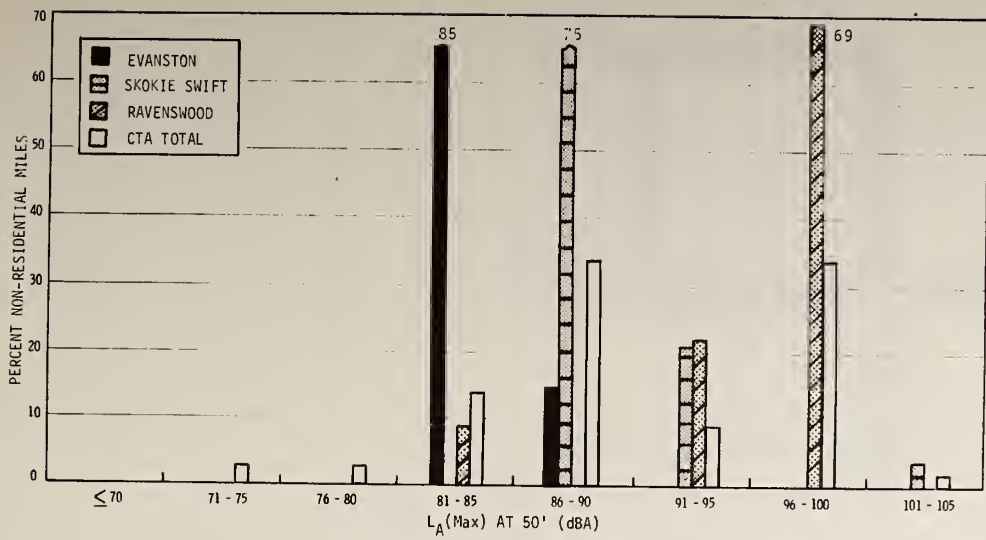



FIGURE F-22B CTA SYSTEM, DISTRIBUTION OF NON-RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

F.4.2 $L_{dn}$ (Trains)

The equivalent day-night sound levels that result only from train pass-bys, $L_{dn}$ (Trains), are illustrated in Figure F-23. This distribution reflects both the $L_A$(Max) pattern described earlier and the number and duration of train pass-bys. The $L_{dn}$(Trains) levels, for the entire CTA system, range from 62 to 87 dBA. The higher levels, 79 to 87 dBA, occur alongside elevated steel track, and, as expected, the lowest (62 dBA) is adjacent to welded, elevated embankment track.

Among similar types of track which exhibit identical $L_A$(Max) values, the $L_{dn}$ (Trains) level may vary. This is caused by a difference in the number of train pass-bys. An increase of 3 dBA in $L_{dn}$ (Trains) level occurs on sections of the North-South and West-Northwest routes and can be attributed to a doubling of both the day and night pass-bys. The elevated steel track on the Ravenswood route exhibits an increase of one dBA when the number of day pass-bys increases significantly.

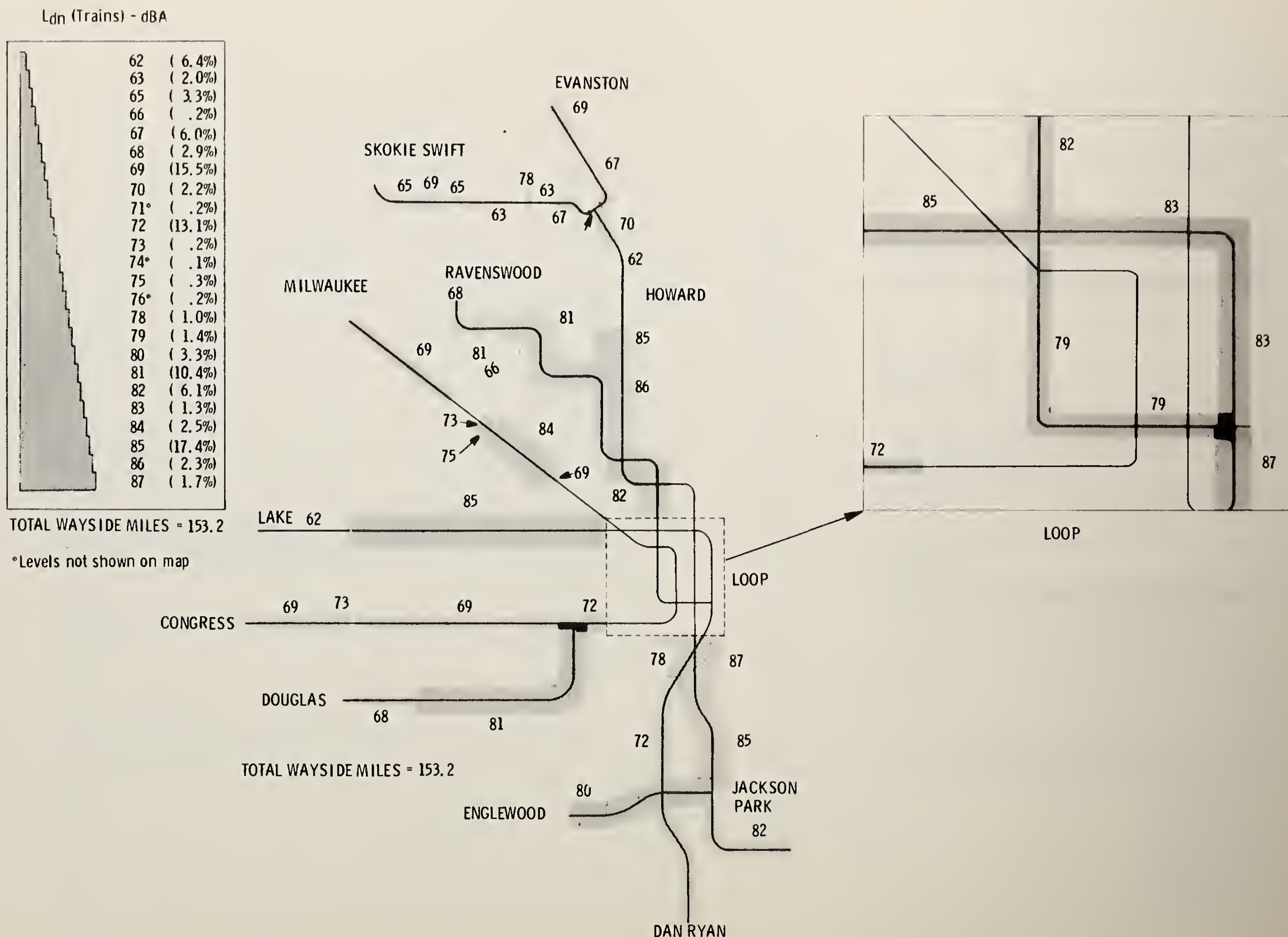



FIGURE F-23 CTA SYSTEM, WAYSIDE $L_{dn}$ (TRAINS)

### F.4.3 $L_{dn}$ (Ambient)

The average $L_{dn}$(Ambient) resulting from all noise sources other than train pass-by noise, which characterizes the noise environments for wayside communities, is 66.0 dBA for CTA. Average $L_{dn}$(Ambient) levels range from a low of 62.4 dBA on the Skokie Swift Service to a high of 67.6 dBA on the North-South route.

### F.4.4 Relative $L_{dn}$

The distribution of residential mileage by Relative $L_{dn}$ level, illustrated in Figures F-24A and F-24B reflects both the pattern of $L_{dn}$(Trains) shown in Figure F-23 and the $L_{dn}$(Ambient) levels discussed earlier.

The Relative $L_{dn}$ levels for the entire CTA system range from one to 36 dBA, with a mean level of 11.1 dBA. Nearly 95 percent of the total CTA residential mileage is exposed to Relative $L_{dn}$ levels between one and 20 dBA, of which 54 percent is greater than ten dBA.

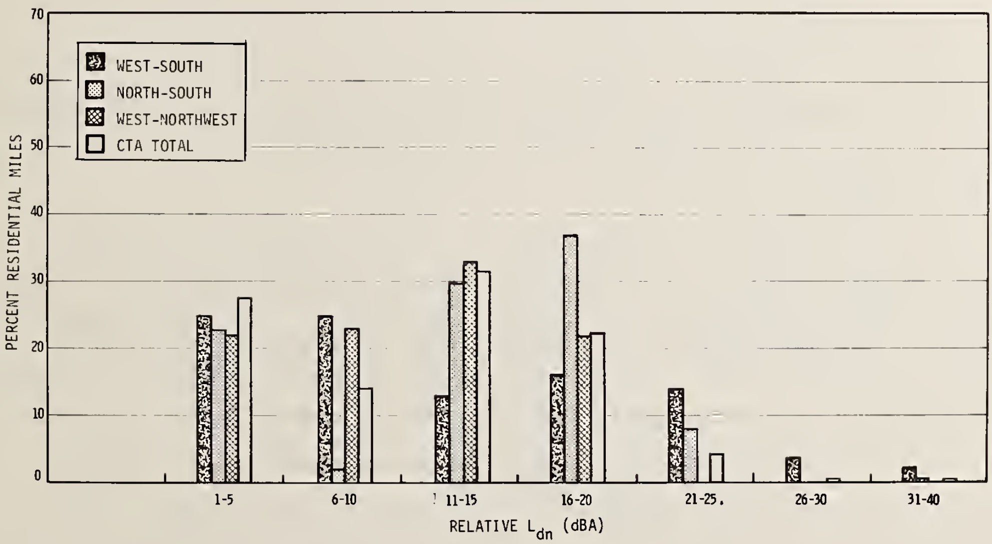



FIGURE F-24A CTA SYSTEM, DISTRIBUTION OF WAYSIDE RELATIVE $L_{dn}$

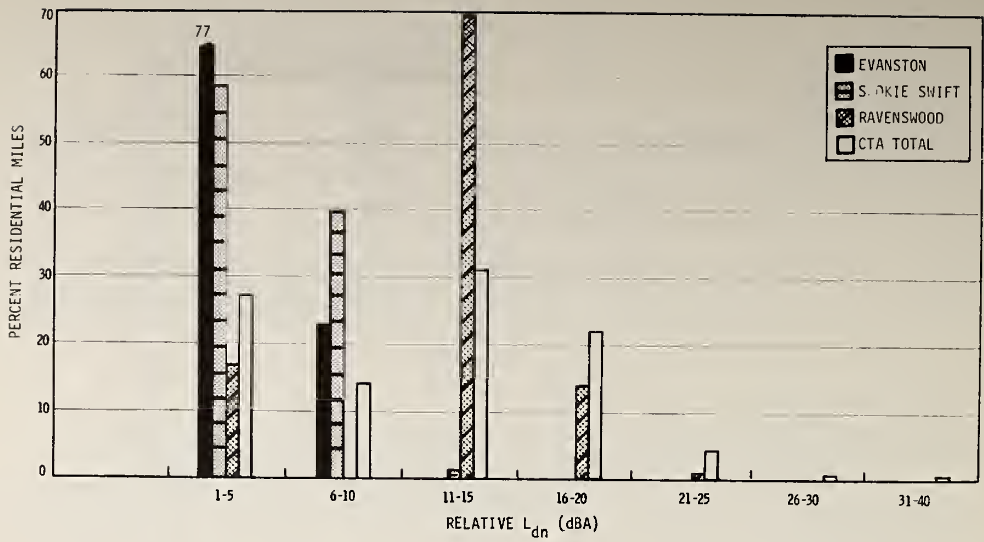



FIGURE F-24B CTA SYSTEM, DISTRIBUTION OF WAYSIDE RELATIVE $L_{dn}$

Approximately 27 percent of the residential mileage experiences low Relative $L_{dn}$ levels (one to five dBA). The majority of these communities (63 percent) abut elevated embankment track (either jointed or welded), with an additional 35 percent adjacent to at-grade track. In these areas, medium $L_{dn}$(Ambient) levels (61 to 70 dBA) are found in combination with medium $L_{dn}$(Trains) levels. Relative $L_{dn}$ levels of six to ten dBA are found in 14 percent of the residential areas. Two types of track predominate, at-grade (77 percent) and open-cut (22 percent). In these communities, medium ambient levels combine with medium or high (71 to 80 dBA) trains levels.

As noted earlier, the majority of the residential mileage has Relative $L_{dn}$ levels of 11 to 15 dBA or 16 to 20 dBA. In both cases, more than 90 percent of the residential areas are situated alongside elevated steel track. Relative $L_{dn}$ levels of 11 to 15 dBA (comprising 31 percent of the CTA residential mileage) are found primarily in communities of medium $L_{dn}$(Ambient) levels exposed to very high $L_{dn}$(Trains) levels (81 to 86 dBA). Low ambient levels (49 to 60 dBA) and medium trains levels also produce the same Relative $L_{dn}$ range. Levels of 16 to 20 dBA (affect-

ing 22 percent of the CTA residential areas) occur in communities where medium ambient levels are combined with high or very high trains levels.

High (21 to 25 dBA) and very high (>25 dBA) Relative $L_{dn}$ levels are found exclusively in communities adjacent to elevated steel track. The high levels, affecting four percent of the residential mileage, are found in communities of medium ambient and very high trains levels. The very high Relative $L_{dn}$ levels, found in only one percent of the residential wayside, occur where low $L_{dn}$(Ambient) levels (49 to 60 dBA) combine with very high $L_{dn}$(Trains) levels.

Of the component routes of the CTA, the West-South route shows the greatest fluctuation in Relative $L_{dn}$ levels, ranging from one to 36 dBA, with a mileage-weighted mean of 11.6 dBA. The ranges and means of the remaining routes are as follows:

| Route | Range | Mean |
|---|---|---|
| North - South | 1 - 24 dBA; | 13.1 dBA |
| West - Northwest | 3 - 20 dBA; | 10.5 dBA |
| Ravenswood | 2 - 24 dBA; | 12.1 dBA |
| Evanston | 4 - 9 dBA; | 5.1 dBA |
| Skokie Swift | 3 - 12 dBA; | 5.2 dBA |

The lines which show the least variations are the Evanston, Skokie Swift, and Ravenswood routes, as shown in Figure F-24B. With the exception of only one percent on the Skokie Swift route, all of the residential mileage adjacent to both the Evanston and Skokie routes is exposed to Relative $L_{dn}$ levels of less than ten dBA. Conversely, nearly 86 percent of the residential areas alongside the Ravenswood route experience levels greater than ten dBA.

### F.4.5 Wayside Exposure

The total population residing within the 60-m (200 ft) corridor adjacent to the aboveground segments of CTA is estimated to be 36,250, of which nearly 43 percent can be found in communities abutting the North-South route.

Figures F-25A and F-25B illustrate the distribution of the wayside population by Relative $L_{dn}$. Less than 0.1 percent of the total population is exposed to the highest Relative $L_{dn}$ levels (>20 dBA), while two-thirds of the population experiences Relative $L_{dn}$ levels between ten and 20 dBA.

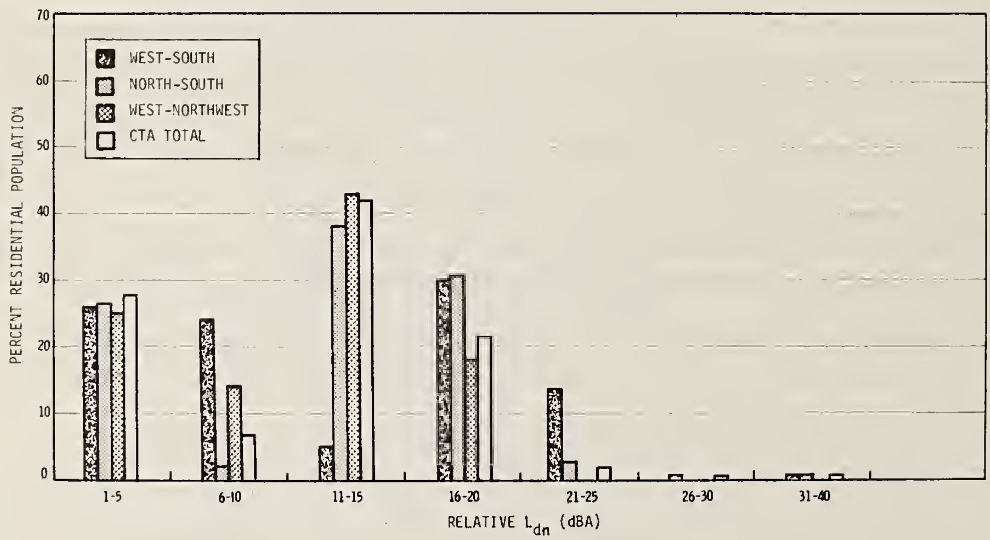



FIGURE F-25A CTA SYSTEM, WAYSIDE NOISE EXPOSURE

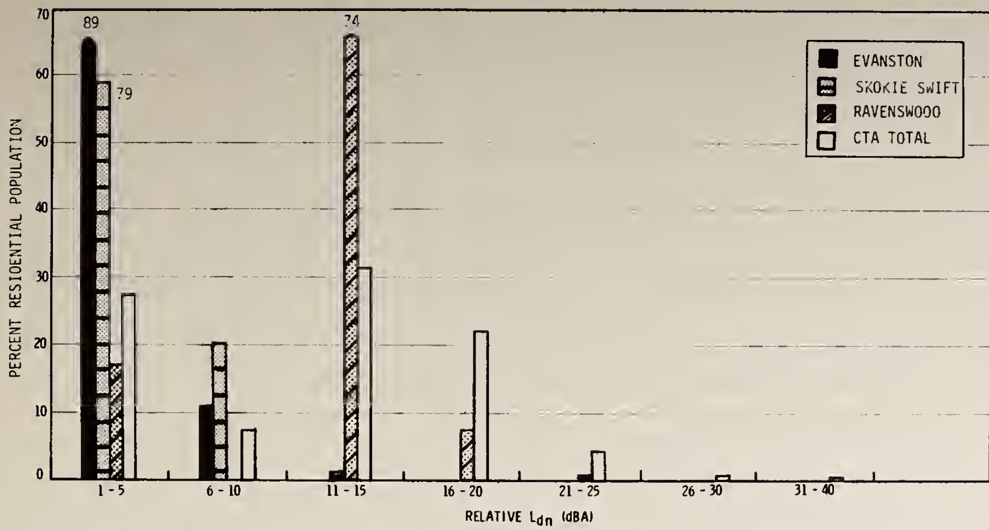



FIGURE F-25B CTA SYSTEM, WAYSIDE NOISE EXPOSURE

## F.4.6 Comparison of CTA Wayside $L_A$(Max) with APTA Guidelines

Figure F-26 shows the distribution of wayside $L_A$(Max) relative to the APTA goals for residential and non-residential areas abutting the rail right-of-way. Only six percent of the non-residential and three percent of the residential communities have levels below the established guideline levels, although 48 percent of the non-residential and 17 percent of the residential areas have levels within ten dBA of the APTA goals. Most of the residential areas (51 percent) are exposed to levels of 21 dBA or greater.

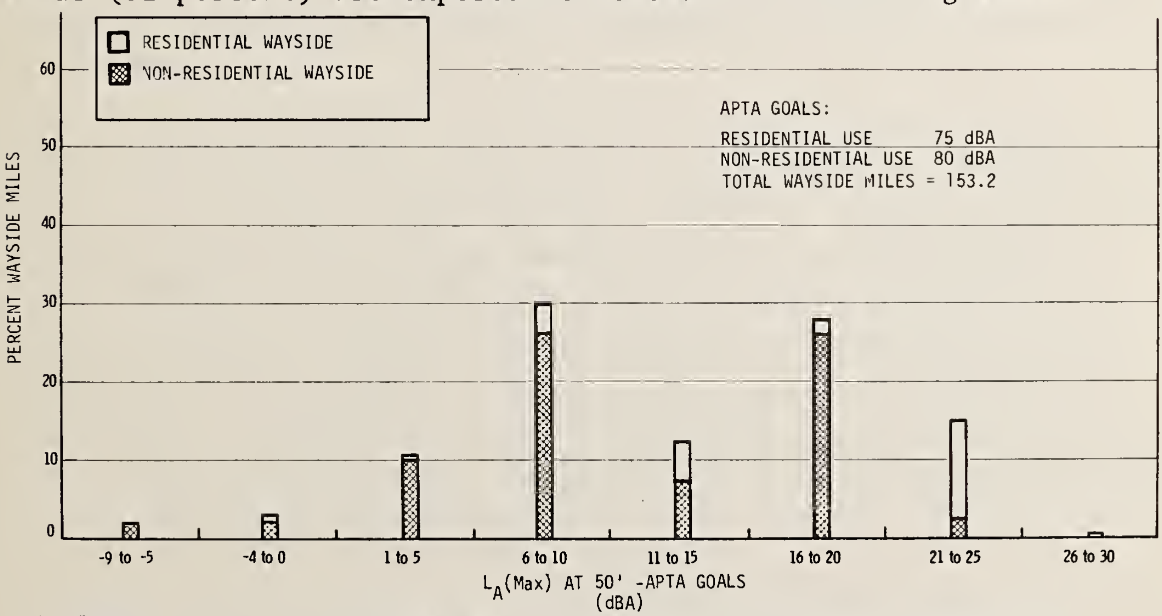



FIGURE F-26 CTA SYSTEM, WAYSIDE NOISE GUIDELINE COMPARISON

# APPENDIX G - URBAN RAIL NOISE ASSESSMENT OF NYCTA SYSTEMS

## G.1 SYSTEM DESCRIPTION (See Table G-1)

This section describes the physical characteristics of the New York City Transit Authority (NYCTA) and the Staten Island Rapid Transit Operating Authority (SIRT). The Port Authority Trans-Hudson Corporation (PATH) is not included because the noise data obtained was insufficient for the purposes of this report.

The NYCTA owns and operates 27 rapid transit routes serving the boroughs of Manhattan, Brooklyn, Queens and the Bronx. The system is comprised of approximately 368 km (230 mi) of right-of-way (700 single track miles) 1120 km, with 60 percent underground, 30 percent elevated and the remaining 10 percent divided among at-grade, open-cut or elevated embankment track. Rail transit in the borough of Staten Island is controlled by SIRT. Total route mileage on this system is approximately 25.6 km (16 mi), with three percent underground, 24 percent elevated embankment, and 73 percent evenly distributed between at-grade and open-cut track (See Table G-1).

Some changes in the overall NYCTA operation have been introduced since the noise data was collected. Two routes, the IND-EE and the BMT-K, were discontinued; their route mileages were incorporated into remaining lines. The BMT-Culver Shuttle was eliminated altogether.

For the purpose of this report, two routes of the NYCTA, the IND-D and the IRT-#5, were chosen to represent the community, in-car, and in-station noise exposure, whereas a sampling of stations and car models was used to characterize the in-station and in-car maximum sound levels for the total system. The NYCTA's "D" and #5 routes account for 20 percent of the right-of-way and 14 percent of the residential mileage; they use 15 percent of all stations. In addition, 21 of the 36 station configurations and all three of the vehicle classifications are represented on these two routes (see Figure G-1).

TABLE G-1 NEW YORK SYSTEM SUMMARY (1 OF 2)

| | NYCTA | | | SIRT |
|---|---|---|---|---|
| A. ROUTE PHYSICAL | | | | |
| 1. Length | 230 Miles | | | 16.5 Miles |
| 2. Track Type | Jointed Rail | | | |
| 3. Track Structure Mileage | | | | |
| a. Underground | 137 Miles | | | .5 Miles |
| b. Steel EL | 65 Miles | | | |
| c. Concrete EL | 5 Miles | | | |
| d. At-Grade | 10 Miles | | | 6 Miles |
| e. In-Cut | 9 Miles | | | 6 Miles |
| f. Elevated Embankment | 4 Miles | | | 4 Miles |
| 4. Number of Stations | 461 | | | 22 |
| B. VEHICLES | IRT | R-44/R-46 | Non-IRT, Non-R-44 | R-44 |
| 1. Year Manufactured | 1948-63 | 1972/76 | 1932-70 | 1972 |
| 2. Number in Service | 2350/12 | 300/576 | 2540/610 | 52 |
| 3. Acoustical Treatment | No/Yes | Yes/Yes | No/Yes | Yes |
| C. SYSTEM SCHEDULING | IND-D | | IRT #5 | |
| 1. Running Time | 80 Minutes | | 59 Minutes | |
| 2. Average Running Speed | 35 mph - Local<br>40 mph - Express | | 35 mph | |

TABLE G-1 NEW YORK SYSTEM SUMMARY (2 OF 2)

| | | | |
|---|---|---|---|
| D. POPULATION DATA | IND-D | IRT-#5 | |
| 1. Daily Ridership | 238,649/day | 125,832/day | |
| 2. Wayside Population Density (Mean) | 54,190/sq. mi. | 53,182/sq. mi. | |
| 3. Wayside Population Within 200 ft. | 14,130 Persons | 8,280 Persons | |
| 4. Residential Land Use (Length-% of Total Wayside) | 8.7 - (61%) | 5.1 - (35%) | |
| E. IN-CAR SOUND LEVELS | Non-R-44/R-44 | | |
| 1. Average Inter-station $L_A$(Max) | 96/81 dBA | 94.4 dBA | |
| 2. $L_A$(Max) Standard Dev. | 5.33/3.74 dBA | 3.64 | |
| 3. $L_{eq}$(R) | 93.1 dBA/79.2 dBA | 93.5 dBA | |
| F. IN-STATION SOUND LEVELS | | | TOTAL NYCTA SYSTEM |
| 1. Average Station $L_A$(Max) | 99 dBA | 99 dBA | 99.5 dBA |
| 1.5 Range of $L_A$(Max) | 85-110 dBA | 85-110 dBA | 83-112 dBA |
| 2. Average Station $L_{eq}$ | 86.76 dBA | 86.43 dBA | |
| G. WAYSIDE COMMUNITY SOUND LEVELS | | | Total D and #5 |
| 1. Average $L_A$(Max) @ 50' | 88.8 dBA | 83.8 dBA | 86.9 dBA |
| 1.5 $L_A$(Max) Range @ 50' | 84-102 dBA | 76-92 dBA | 76-102 dBA |
| 2. Average $L_{dn}$ (Trains) | 78.3 dBA | 72.5 dBA | 75.4 dBA |
| 3. Average $L_{dn}$(Ambient) | 68.9 dBA | 69.9 dBA | 69.3 dBA |
| 4. Average Relative $L_{dn}$ | 8.2 dBA | 5.0 dBA | 7.0 dBA |

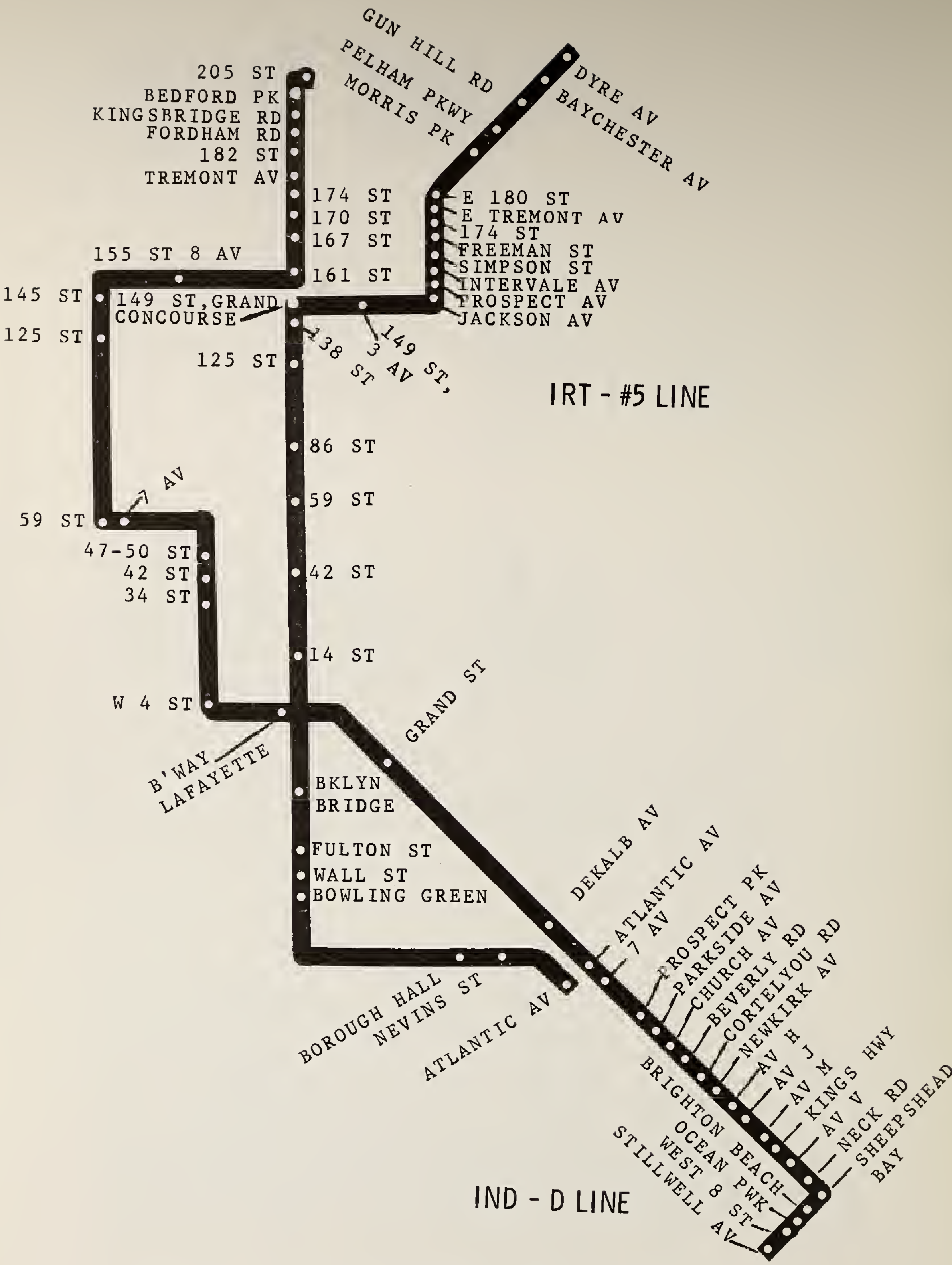



FIGURE G-1 NYCTA SYSTEM, IND-D, IRT-#5 LINES

Seventeen different types of track construction are employed throughout the system, from single tracks directly mounted on a concrete base in tunnels to concrete elevated tracks on ballast with wood ties. The one feature in common on the NYCTA system is that all rail is jointed.

Approximately 75 percent of the trackbed on the SIRT is ballast and ties, with the balance cinders and ties. Jointed rail accounts for 76 percent of the system, with the remainder being welded rail.

### G.1.1 Stations

At the time the noise measurements were taken, the NYCTA Rapid Rail system consisted of 463 stations, divided into 36 different configurations, the most prevalent type being the side platform (either two or four-tracked). Due to the elimination of the BMT-Culver Shuttle, there are presently only 461 stations in use throughout the NYCTA.

The SIRT route has 22 stations, with one multi-platform, 4 center platform, and 17 side platform configurations.

### G.1.2 Transit Vehicles

The transit fleet is comprised of approximately 6,800 rail vehicles, covering 22 different car models. For noise assessment purposes, these can be grouped into three classifications: R-44 cars; IRT cars; and non-IRT, non-R-44 cars. The R-44 cars, nearly five percent of the fleet, were built in 1972. They are 22.8 km (75 ft) long and are acoustically treated. The R-44 vehicles are the only rail cars operated on SIRT.

The IRT cars, which comprise 36 percent of the fleet, were built during the following years: 1948-50, 1955-59, and 1960-63. They are 15.5 m (51 ft) long and are not acoustically treated. The The last category, vehicles which are neither R-44 nor IRT. were built in 1948, 1955. 1960-64, and 1966-70. These cars are all 18.2 m (60 ft) long. Two-thirds of the cars constructed after 1966

are air-conditoned and have sealed windows; the remaining 80 percent of the non-IRT, non-R-44 vehicles have no accoustical treatments.

Two changes in car models took place after the noise measurements were compiled. A new vehicle, the R-46, which has the same properties as the R-44 cars, was introduced. Approximately 600 of these vehicles are now operating on the NYCTA system, and consequently, older, non-IRT, non-R-44, cars have been retired. The R-44/46 model cars now make up approximately 15 percent of the NYCTA fleet.

The other change involves the introduction of 12 prototype vehicles on the IRT routes. These are IRT cars which have been supplied with acoustical treatment. The NYCTA plans to convert the entire IRT fleet if the prototypes prove successful.

### G.1.3 Route Description

The IND-D travels from its northern terminal at 205th Street in the Bronx, through Manhattan, to its southern terminal at Stillwell Avenue in Brooklyn. The line is 41.3 km (25.8 mi) in length and proceeds underground through the Bronx and Manhattan to Prospect Park in Brooklyn, 29.9 km (18.7 mi). From here to Avenue H, this line traverses open-cut track, 3.5 km (2.2 mi). The line then proceeds on elevated embankment track to Sheepshead Bay, 4.8 km (3.0 mi). The final section to the terminus at Stillwell is on elevated steel track, 3.0 km (1.9 mi) (See Figure G-2.)

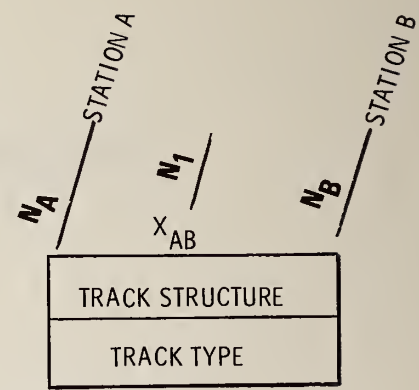
The track construction in the subway tunnels is primarily wood block ties set in concrete, with the aboveground sections on ballast and wood ties. This route employs two classes of rail vehicles, both the R-44 car, (44 percent), and the non-IRT, non R-44 car.

Running time from 205th Street to Stillwell Avenue is 80 minutes. Average train speeds are 56 km/h (35 mph) for local trains and 64 km/h (40 mph) for express.

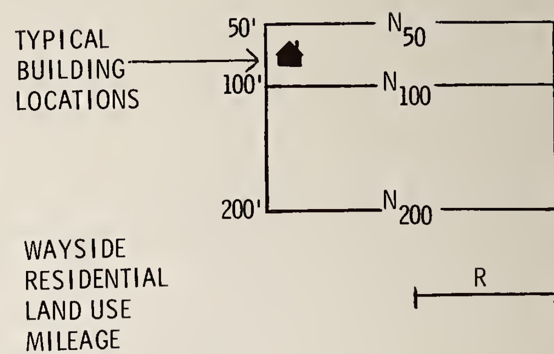
## LEGEND FOR FIGURES G-2 AND G-3

TRACK STRUCTURE

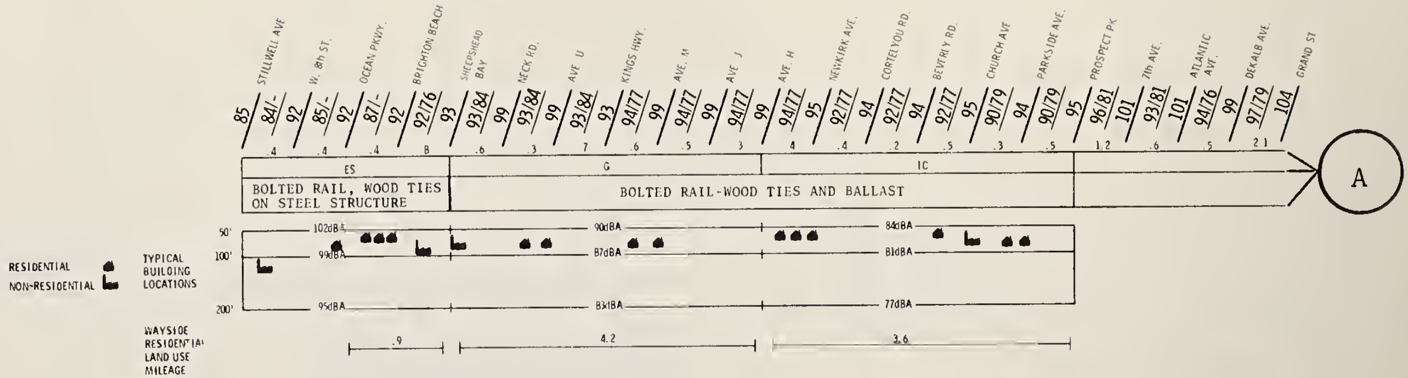
| | | |
|---|---|---|
| ES | = | ELEVATED STEEL |
| EE | = | ELEVATED EMBANKMENT |
| UG | = | UNDERGROUND |
| CV | = | CONCRETE VIADUCT |
| IC | = | IN CUT |
| AG | = | AT GRADE |
| MS | = | MEDIAN STRIP |
| EC | = | ELEVATED CONCRETE |
| A | = | AERIAL |




| | | |
|---|---|---|
| $X_{AB}$ | = | INTERSTATION DISTANCE (MILES) |
| $N_A/N_B$ | = | STATION NOISE AT STATION A/B (dBA) |
| $N_i$ | = | IN-CAR NOISE (dBA) |
| $N_{50}$ | = | WAYSIDE NOISE AT 50 FEET (dBA) |
| $N_{100}$ | = | WAYSIDE NOISE AT 100 FEET (dBA) |
| $N_{200}$ | = | WAYSIDE NOISE AT 200 FEET (dBA) |
| R | = | WAYSIDE RESIDENTIAL LAND USE MILEAGE (BOTH SIDES OF TRACK) |




DATA UNIQUE TO PARTICULAR SYSTEMS ARE NOTED ON SYSTEM SCHEMATICS




NOTES:
TRACK STRUCTURE:
G = AT-GRADE OR ELEVATED EMBANKMENT

IN-CAR NOISE LEVELS $N_1/N_2$
$N_1$ = NON-IRT, NON-R-44 CARS
$N_2$ = R-44 CARS

FIGURE G-2A NYCTA SYSTEM, IND-D ROUTE

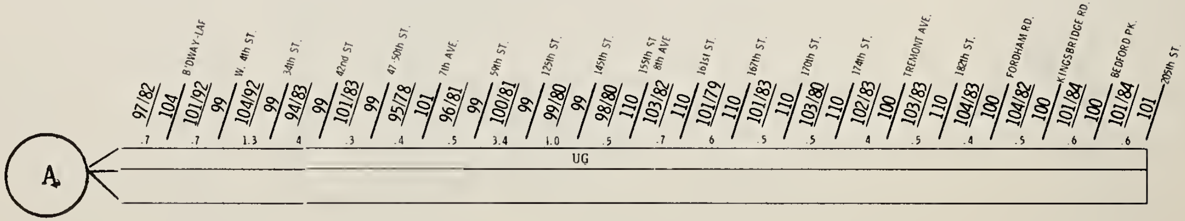



FIGURE G-2B NYCTA SYSTEM, IND-D ROUTE

Headways on the IND-D route, disregarding other routes sharing the same trackage, range from seven to 40 minutes. Each train has four, six, or ten cars.

For the purposes of this report, the IRT #5 route was studied from Dyre Avenue in the Bronx, through Manhattan, to Atlantic Avenue in Brooklyn. It serves areas east of the D route, and is 3.17 km (19.8 mi) in length. This line proceeds from Dyre Avenue to E. 180th Street along at-grade, 3.7 km (2.3 mi), and open-cut, 2.7 km (1.7 mi) track. From here, until it enters the subway portal at 149th Street, the line runs along steel elevated track, 5.3 km (3.3 mi). It then travels underground to Atlantic Avenue, 20 km (12.5 mi) (See Figure G-3).

The track construction in the subway sections is wood ties in concrete invert and, in the aboveground areas, ballast and wood ties. Only the IRT cars are used on this route.

Running time from Dyre to Atlantic Avenues is 59 minutes. Average train speed is 56 km/h (35 mph). Headways range from five to 20 minutes using either five or ten cars per train.

## G.2 IN-CAR NOISE

### G.2.1 $L_A$(Max)

The distribution of route miles by in-car $L_A$(Max), shown in Figure G-4, illustrates the effect of type of track structure and vehicle on the SIRT, the IND-D and IRT-#5, which are the two representative lines of the NYCTA system.

Examining the SIRT system, one finds that no in-car noise plateaus exceed 85 dBA, and the majority of mileage (64 percent) is exposed to $L_A$(Max) levels between 75 and 80 dBA. These relatively low levels are due to two factors: only three percent of the route is underground, and more importantly, only the R-44 vehicle is used on the route. The significance of car and track type in determining in-car noise levels becomes more apparent upon examination of the noise levels on "D" and #5 routes. Nearly 41 percent of the "D" route mileage experienced $L_A$(Max) levels below 86 dBA, whereas none of the #5 mileage had levels below 86 dBA.

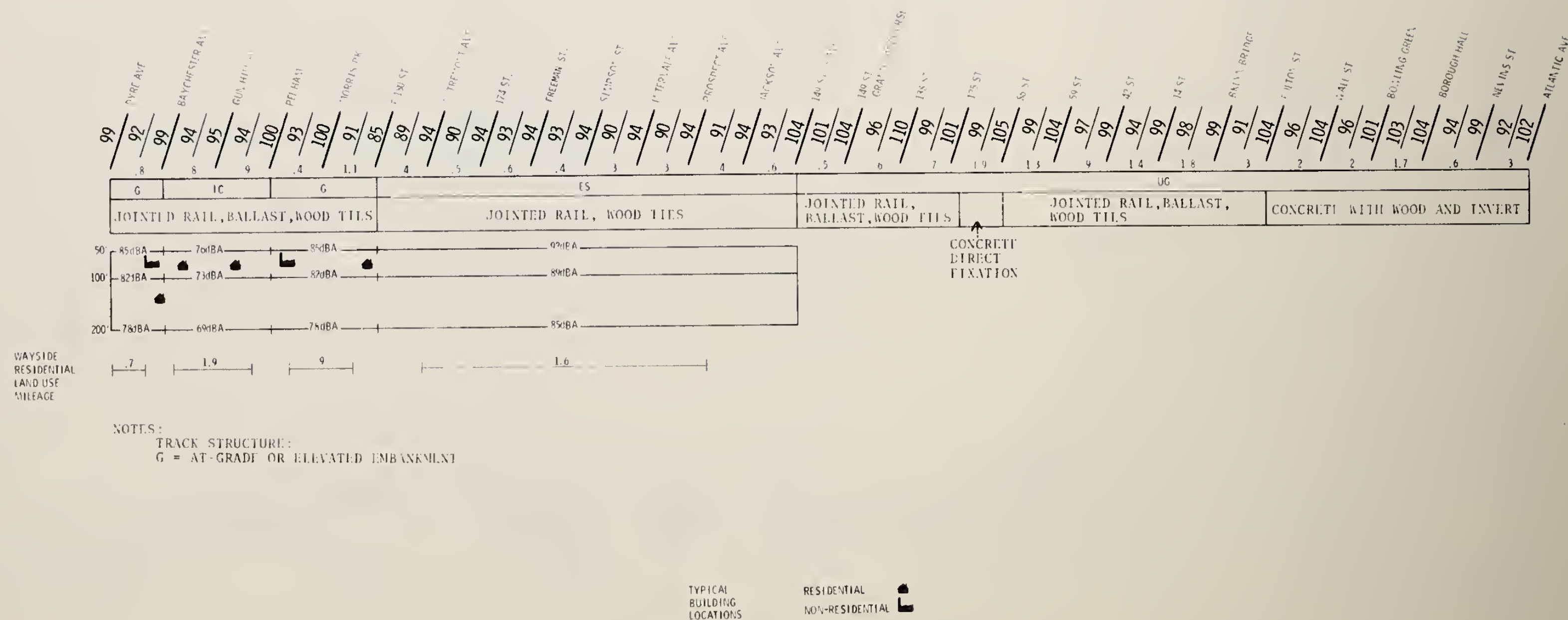



FIGURE G-3 NYCTA SYSTEM, IRT-#5 LINE

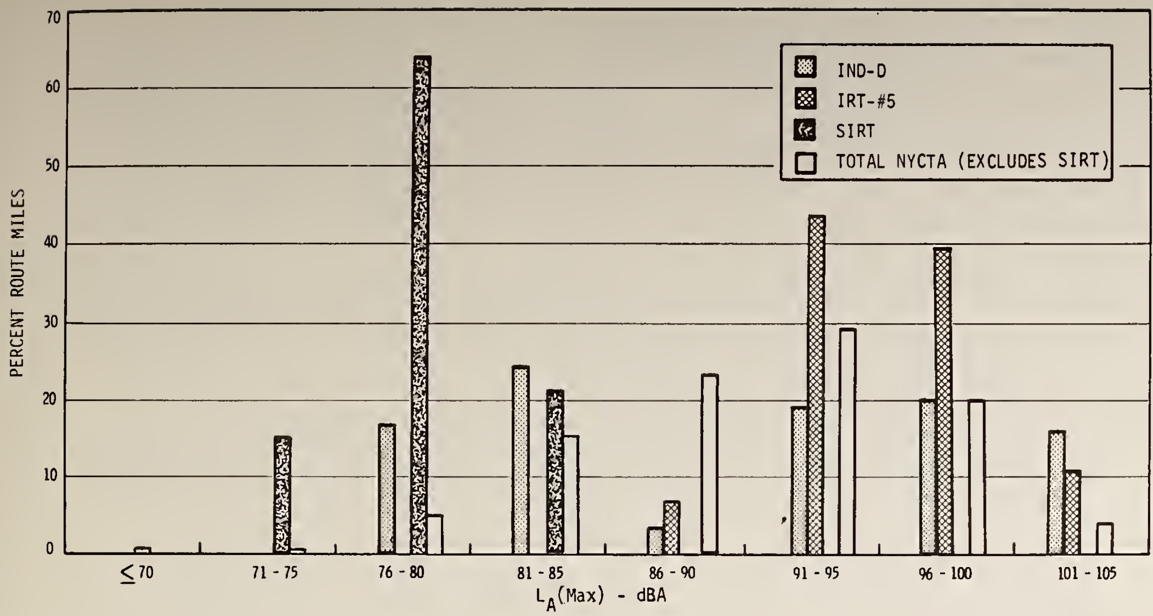



FIGURE G-4 NYCTA SYSTEM, DISTRIBUTION OF IN-CAR PLATEAU NOISE LEVELS

Approximately 42 percent of the vehicles in use on the "D" route are R-44's, while only the IRT model cars operate on the #5. Table G-2 shows the relationship between car types on varying types of track for the two routes. On the average, the $L_A$(Max) levels for the R-44 vehicles are between 11 and 17 dBA less than those for the other vehicle classifications. The high peaks noticed on the #5 route in the 91 to 95 and 96 to 100 dBA ranges reflect the fact that the noisier IRT model car is employed, and that nearly 63 percent of the route is underground, where $L_A$(Max) levels are generally five dBA higher than on other types of track.

TABLE G-2 NEW YORK IN-CAR NOISE SUMMARY

| | UNDERGROUND | ELEVATED STEEL | IN-CUT | EMBANKMENT |
|---|---|---|---|---|
| IRT Car | 98 dBA | 92 dBA | 94 dBA | 92 dBA |
| Non-R44, Non-IRT Car | 99 dBA | 88 dBA | 92 dBA | 94 dBA |
| R44 Car | 82 dBA | 76 dBA | 78 dBA | 81 dBA |

(Based on noise levels on IND-D and IRT-#5 lines of NYCTA)

### G.2.2 In-Car Equivalent Noise Levels

The route equivalent level, $L_{eq}(R)$, characterizing the in-car noise environment for a complete end-to-end trip is 93.5 dBA for the IRT-#5 and 93.1 and 79.2 dBA for non-R-44 and R-44 cars, respectively, which operate on the IND-D.

Figure G-5 illustrates the distribution of route miles by inter-station $L_{eq}$ for the two representative lines. It is derived from the $L_A$(Max) distribution (Figure G-4), and thus the same patterns evolve. The "D" route exhibits the full spectrum of $L_{eq}$ levels, whereas the #5 route is clustered between levels of 86 to 100 dBA.

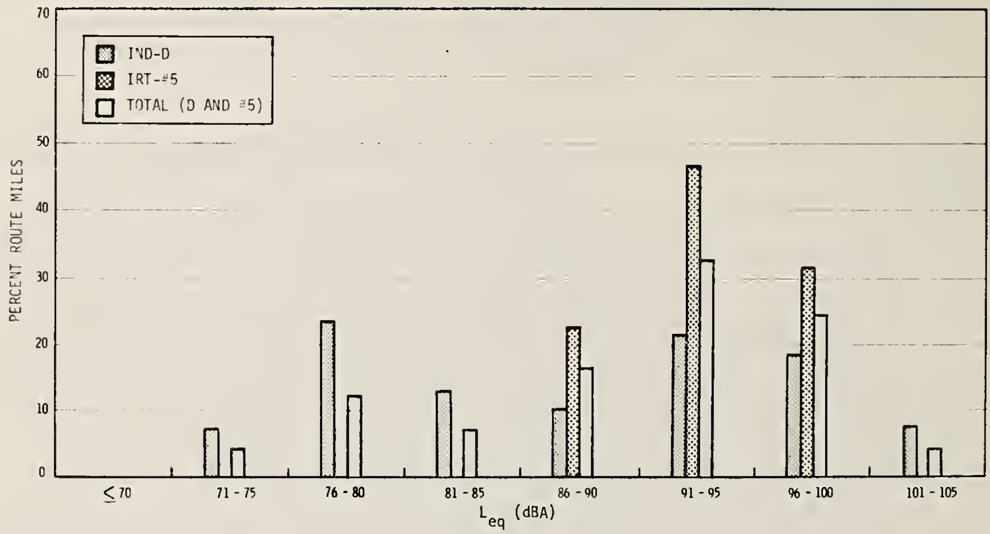



FIGURE G-5 IND-D AND IRT-#5, DISTRIBUTION OF IN-CAR EQUIVALENT SOUND LEVELS

### G.2.3 In-Car Exposure

Figure G-6 represents an estimate of in-car exposure, expressed as people-hours, for the two representative routes versus inter-station $L_{eq}$. Given accurate trip time information, one can determine the average time and total number of patrons exposed to each $L_{eq}$ level. The people-hours are distributed throughout the $L_{eq}$ spectrum, with the majority (58 percent) exposed to levels greater than or equal to 91 dBA.

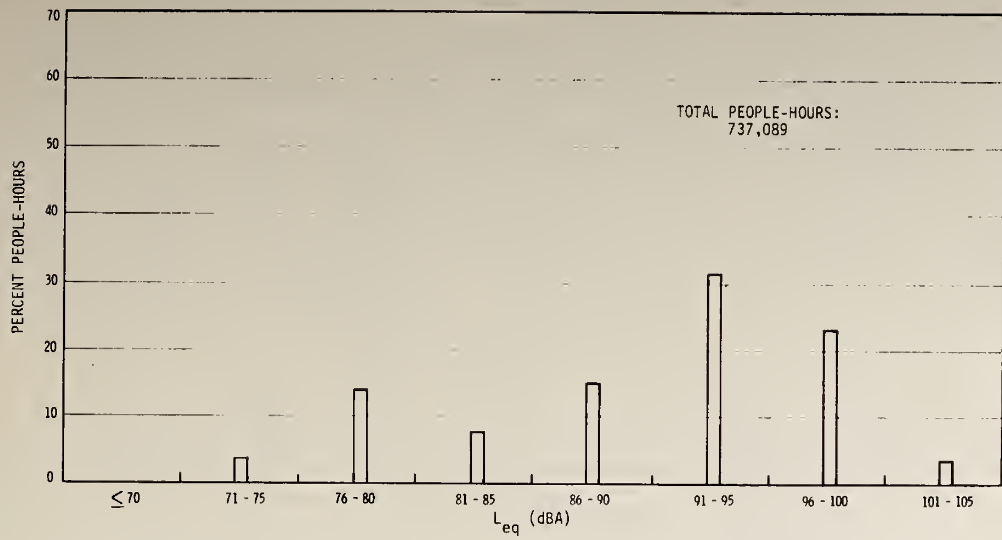



FIGURE G-6 IND-D AND IRT-#5, IN-CAR NOISE EXPOSURE

G.2.4 Comparison of IND-D and IRT-#5 In-Car $L_A$(Max) with APTA Guidelines

The difference between the measured in-car $L_A$(Max) and the APTA goals as a percentage of route miles is illustrated in Figure G-7. Only eight percent of the mileage is below the established guidelines level, with nearly 60 percent more than 15 dBA higher. Subway mileage is represented in all categories except for the six to ten dBA range, although nearly two-thirds of the underground mileage is contained in the 16 to 20 and 21 to 25 dBA ranges. Only elevated steel mileage is represented in the six to ten dBA range.

## G.3 STATION NOISE

### G.3.1 $L_A$(Max) and $L_{eq}$

The highest in-station $L_A$(Max) levels are recorded in subway stations. No underground station on the entire NYCTA system has a recorded level of less than 98 dBA. The lowest levels can be found on concrete elevated and at-grade stations, 91 dBA. The average station arrival and departure sound levels for other types of track are elevated steel (93 dBA), in-cut (95 dBA) embarkment (97 dBA), and underground (105 dBA).

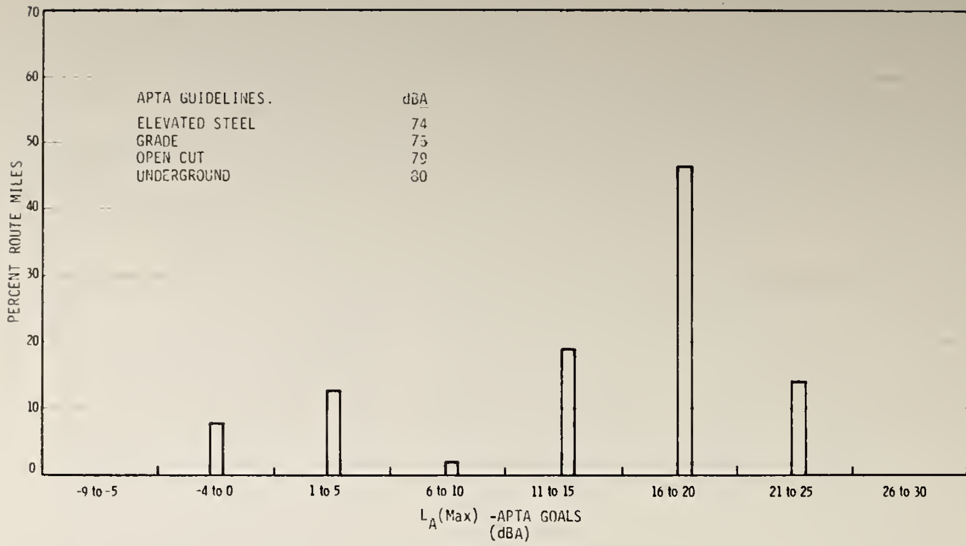



FIGURE G-7 IND-D AND IRT-#5, IN-CAR NOISE GUIDELINE COMPARISON

Figure G-8 illustrates the percent stations distributed over the $L_A$(Max) ranges. Nearly 73 percent of all stations experience $L_A$(Max) levels between 91 and 100 dBA, including the majority of all the aboveground stations regardless of type of track. Only about three percent of such stations exhibit $L_A$(Max) levels greater than 100 dBA.

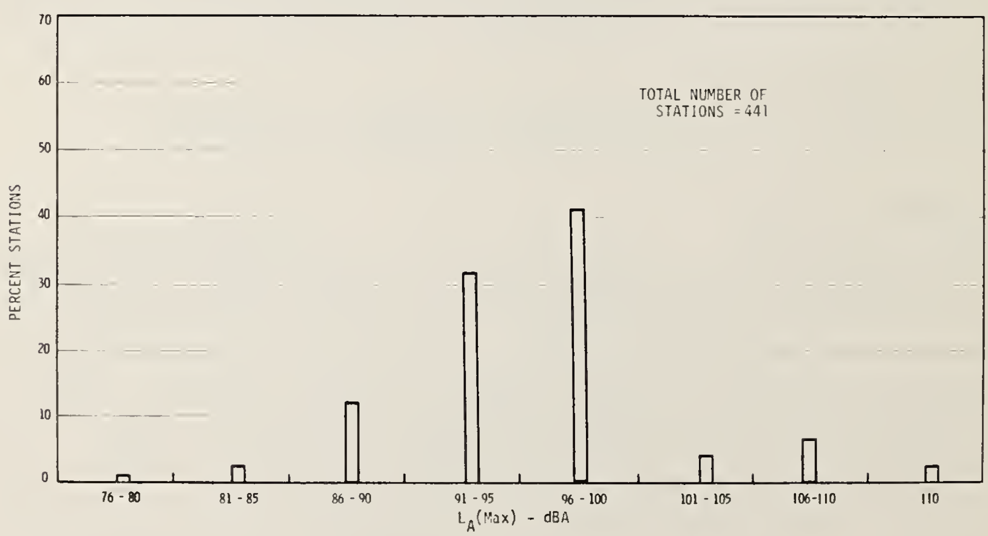



FIGURE G-8 NYCTA SYSTEM, IN-STATION MAXIMUM NOISE LEVELS

The distribution of station $L_{eq}$ values is shown in Figure G-9, for the "D" and #5 routes. The elevated steel track has the lowest range in $L_{eq}$ values, from 73 dBA to 82 dBA, with subway stations exhibiting the highest range in levels, from 86 to 97 dBA. Stations which are subjected to express pass-throughs show $L_{eq}$ values generally higher (three to six dBA) than other stations on similar types of track.

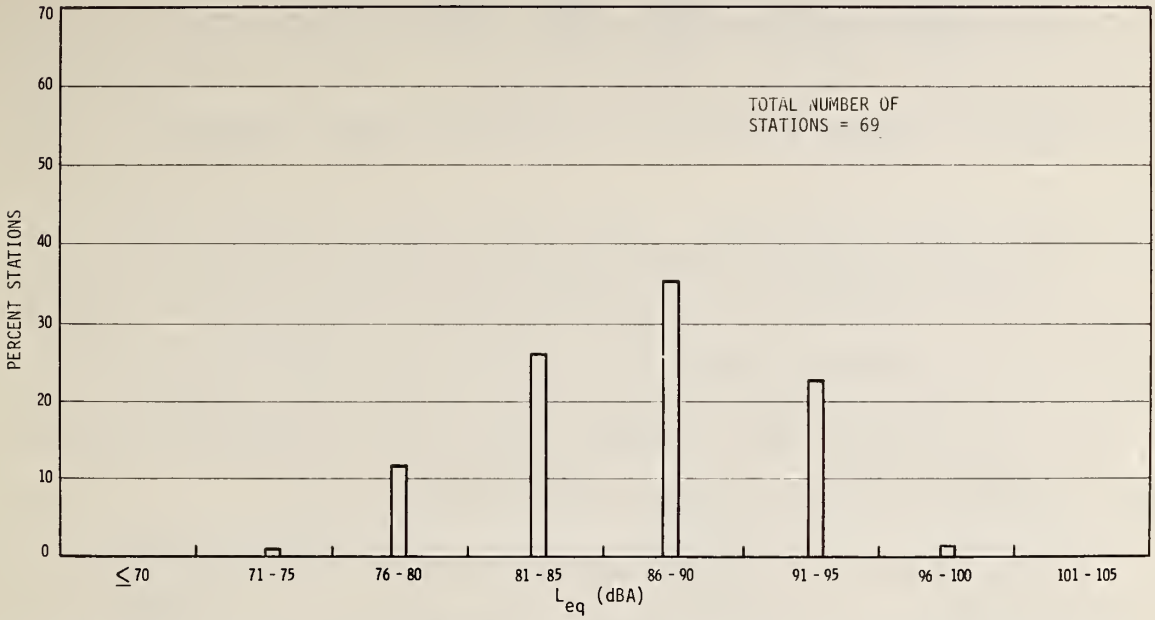



FIGURE G-9 IND-D AND IRT-#5, IN-STATION EQUIVALENT SOUND LEVELS

### G.3.2 In-Station Noise Exposure

Figure G-10, the distribution of patronage versus station $L_{eq}$ levels, illustrates that more than 80 percent of the patrons on both the "D" and #5 experience average noise levels of 86 dBA or greater. Heavy patronage in the "D" Line's underground stations is reflected in the spike at 86 to 90 dBA, and in the #5 subway stations, in the twin peaks in the 86 to 90 and 91 to 95 dBA ranges.

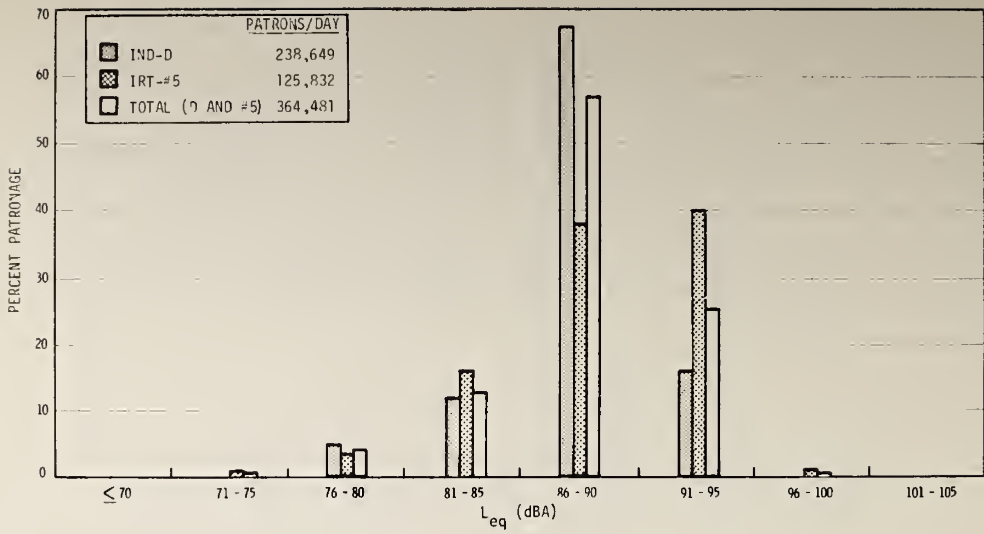



FIGURE G-10 IND-D AND IRT-#5, IN-STATION NOISE EXPOSURE

## G.3.3 Comparison of NYCTA Station $L_A$(Max) with APTA Guidelines

All of the stations in the NYCTA system exceed the APTA guidelines, as shown in Figure G-11, and only two percent of the stations are within ten dBA of the goals. All subway stations are at least 16 dBA higher than the APTA goals, as are approximately three-fourths of the stations on steel elevated track.

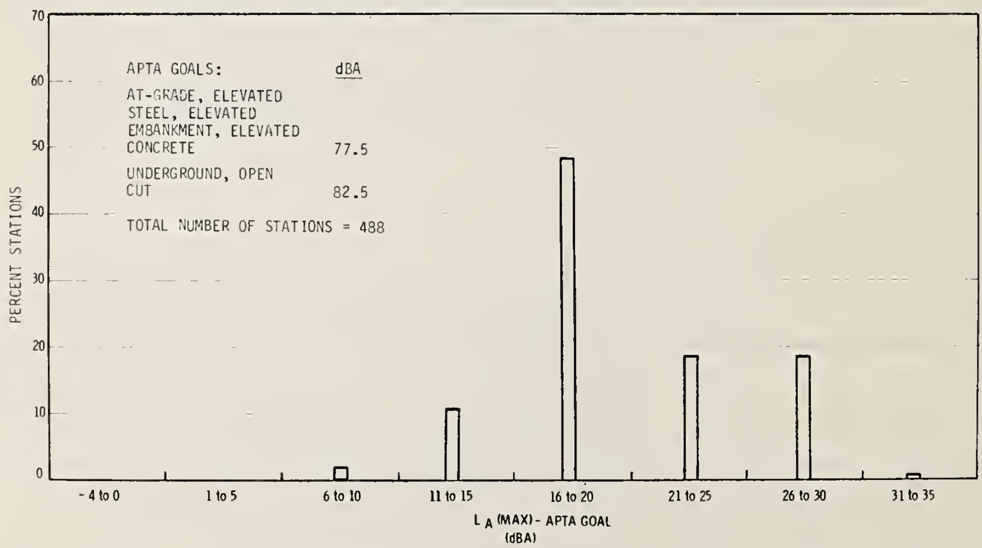



FIGURE G-11 NYCTA SYSTEM, IN-STATION NOISE GUIDELINE COMPARISON

## G.4 NYCTA WAYSIDE NOISE

### G.4.1 $L_A$(Max)

The estimated average A-weighted maximum pass-by levels, $L_A$(Max), for the NYCTA and SIRT systems are as follows:

| | |
|---|---|
| Elevated Steel | 92 dBA |
| Elevated Concrete | 84 dBA |
| Open-Cut | 76 dBA |
| At-Grade | 82 dBA |
| Elevated Embankment | 84 dBA |

The above levels were determined in the following manner: Wayside measurements were taken at selected sites adjacent to various types of track structure on several routes. At each location, mean levels were calculated and then averaged (arithmetically) over each type of track.

It is possible to observe $L_A$(Max) levels which vary from the system-wide averages on individual routes or segments. This is readily seen below where the levels for the "D" route range from six to ten dBA higher than the system-wide averages.

$L_A$(Max) levels for the two representative routes are as follows:

| | IRT-#5 | IND-D |
|---|---|---|
| Elevated Steel | 92 dBA | 102 dBA |
| Open-Cut | 76 dBA | 84 dBA |
| Grade (either at-grade or elevated embankment track) | 85 dBA | 90 dBA |

These levels were calculated by taking a decibel average of the mean $L_A$(Max) levels observed at the wayside locations adjacent to these two routes. Note that no measurements were recorded alongside elevated steel trackage on the #5 route, and therefore the system average, 92 dBA, is assigned to the elevated steel track on this line.

The percentages of residential and non-residential mileage against the wayside $L_A$(Max) level are shown in Figures G-12 and G-13, respectively. The residential mileage adjacent to the #5

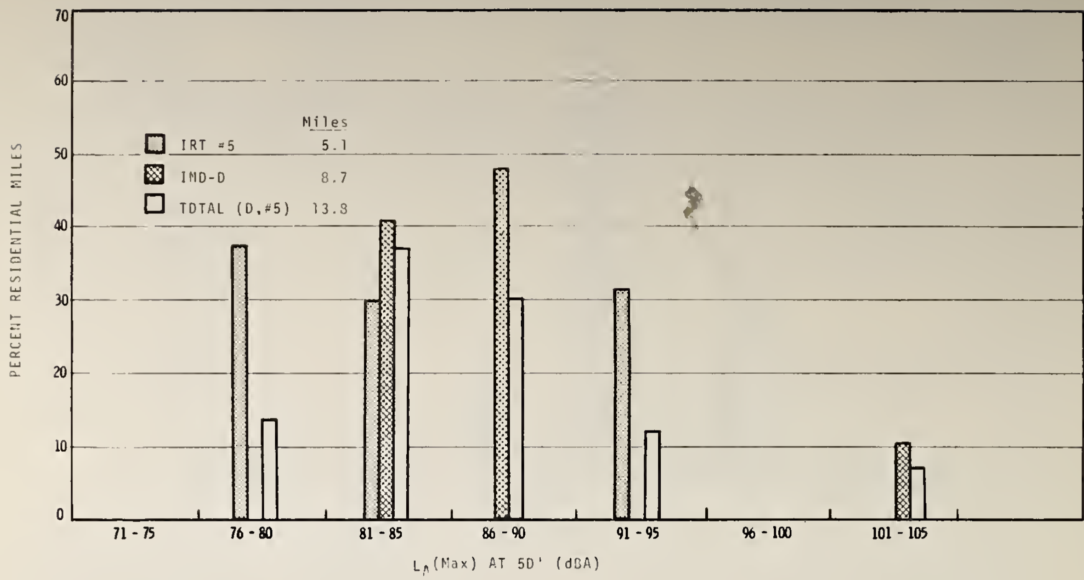



FIGURE G-12 IND-D AND IRT-#5, DISTRIBUTION OF RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

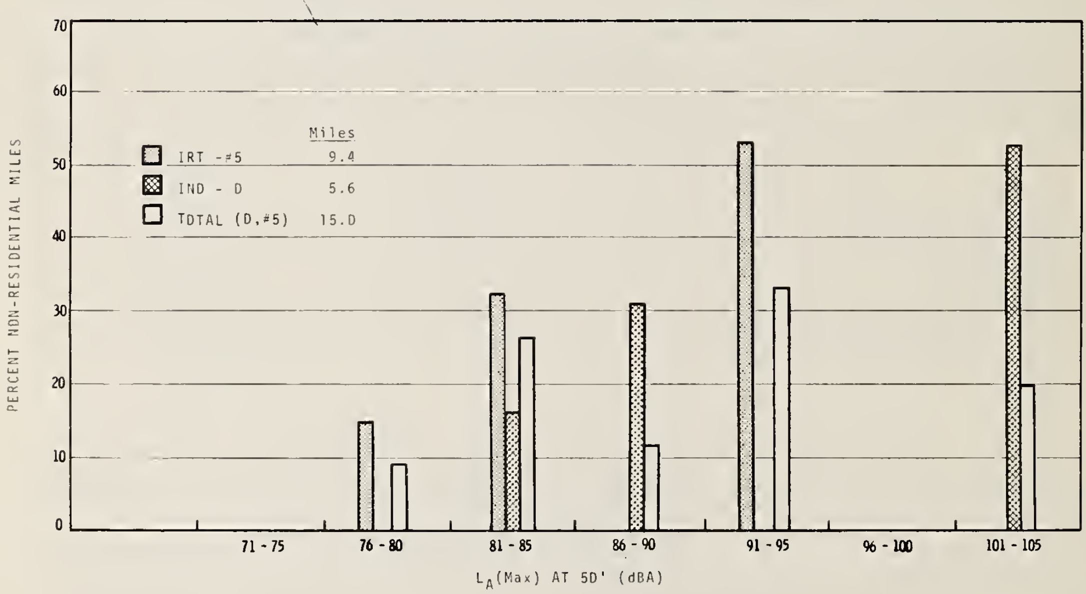



FIGURE G-13 IND-D AND IRT-#5, DISTRIBUTION OF NON-RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

route is evenly distributed among the three types of track, whereas, on the "D" route, approximately 90 percent of the mileage abuts open-cut or grade trackage. A different distribution develops for the non-residential mileage. Along both routes the majority of the non-residental mileage, approximately 53 percent, is adjacent to elevated steel track, with nearly 32 percent alongside grade trackage. The remaining mileage abuts open-cut track, where the lowest $L_A$(Max) levels are observed.

For the NYCTA and SIRT systems, the percentage of residential and non-residential mileage against the $L_A$(Max) levels is shown in Figures G-14 and G-15, respectively. It is evident that the majority (nearly 58 percent) of the aboveground mileage is adjacent to elevated steel track.

### G.4.2 $L_{dn}$(Trains)

The equivalent day-night sound levels that result only from train pass-bys, $L_{dn}$(Trains), are illustrated in Figure G-16. As

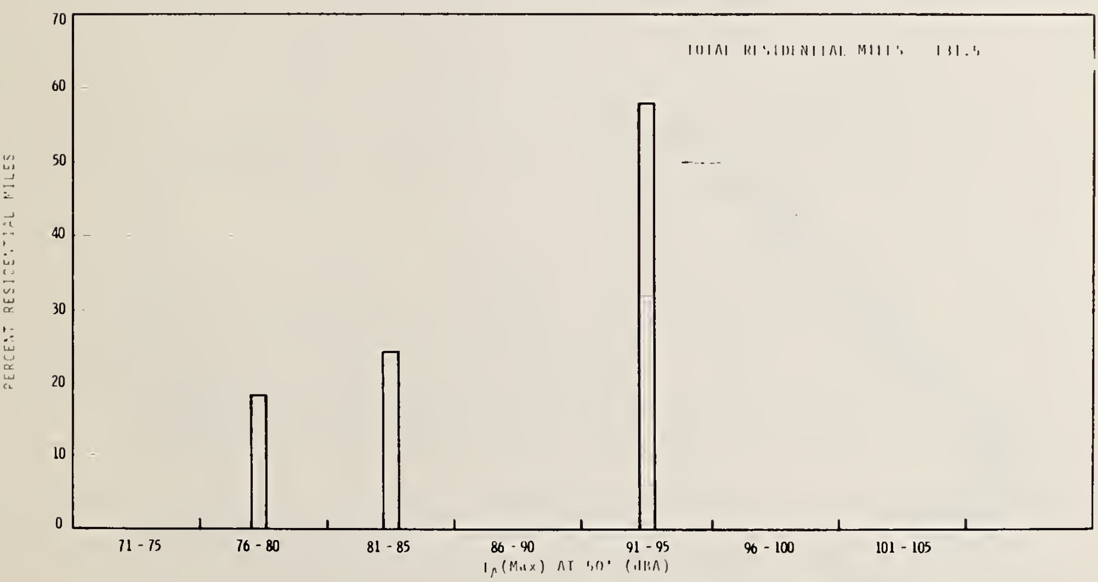



FIGURE G-14 NYCTA SYSTEM, DISTRIBUTION OF RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

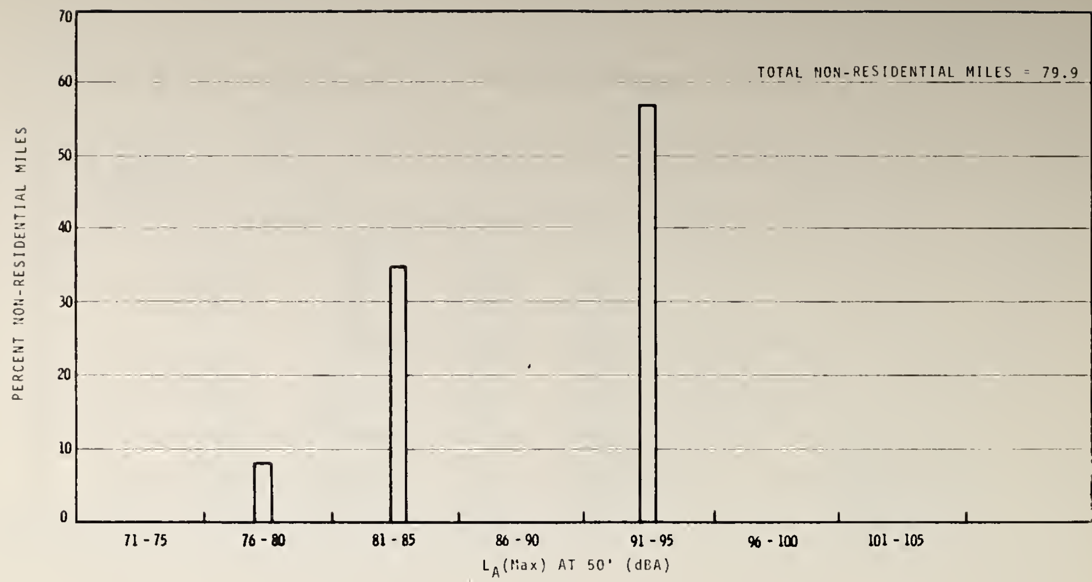



FIGURE G-15 NYCTA SYSTEM, DISTRIBUTION OF NON-RESIDENTIAL WAYSIDE MAXIMUM PASS-BY NOISE LEVELS

a measure of exposure, the $L_{dn}$(Trains) distribution reflects both the $L_A$(Max) pattern discussed earlier, and the number and duration of train pass-bys. As lower wayside $L_A$(Max) levels are observed in communities adjacent to the #5 route, so, too, are lower $L_{dn}$(Trains) levels observed. However, were the $L_A$(Max) levels of both routes equivalent, the "D" route would still have an $L_{dn}$(Trains) level of two dBA higher due to the existence of additional train pass-bys.

The above relationship becomes apparent upon examination of the "D" route. The elevated steel segments register $L_{dn}$(Trains) levels of 88, 89 and 91 dBA. A difference of three dBA is observed when the number of pass-bys (both day and night) is doubled. Doubling only the day or only the night pass-bys produces a difference of one or two dBA in $L_{dn}$(Trains) level, respectively.

The following list summarizes the calculated $L_{dn}$(Trains) levels for the two routes over each type of track.

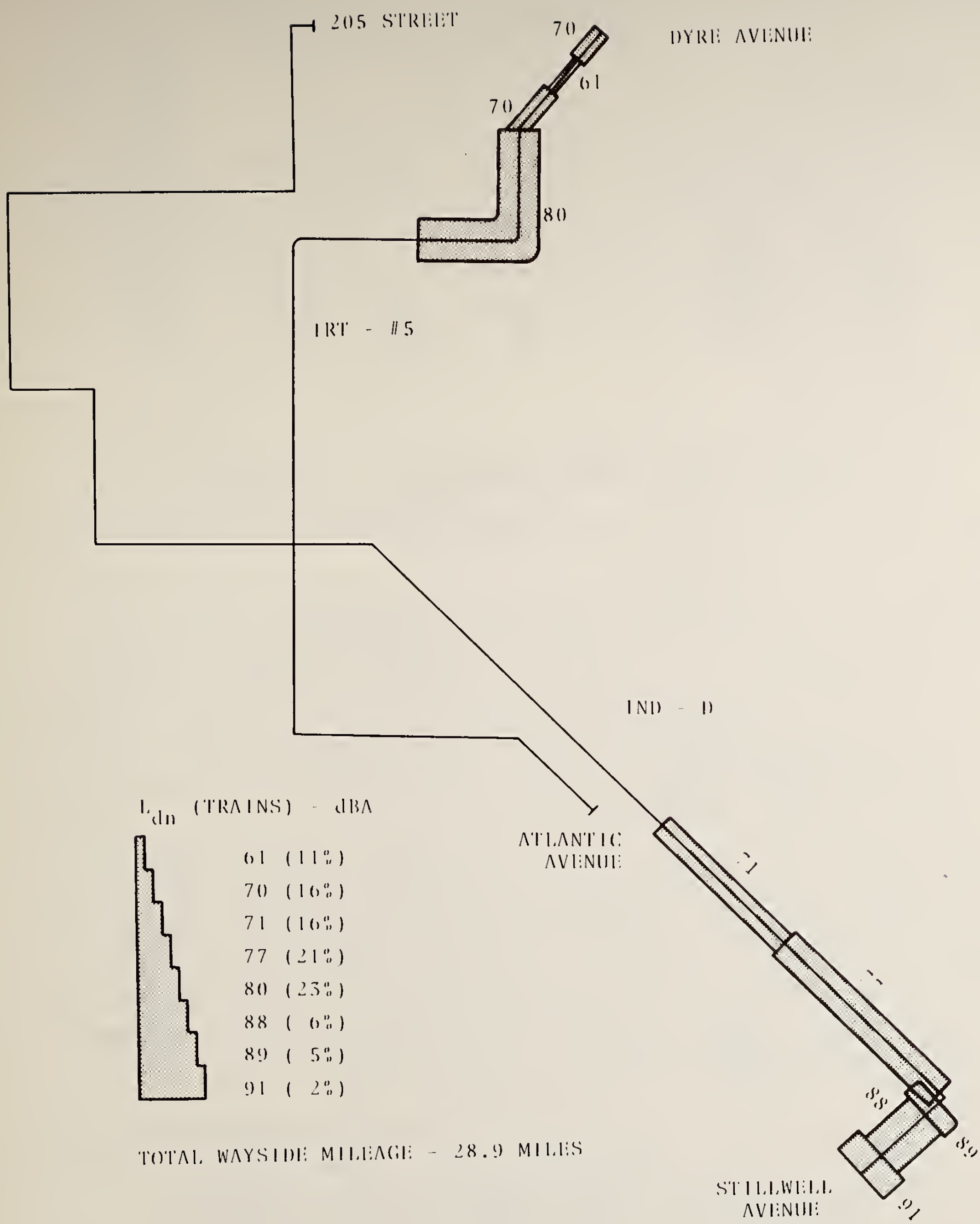



FIGURE G-16 IND-D AND IRT-#5, WAYSIDE $L_{dn}$ (TRAINS)

| | IRT-#5 | IND-D |
|---|---|---|
| Open-Cut | 61 dBA | 71 dBA |
| Grade | 70 dBA | 77 dBA |
| Elevated Steel | 80 dBA | 88, 89, 91 dBA |

### G.4.3 $L_{dn}$(Ambient)

The average $L_{dn}$(Ambient) levels, which are used to characterize the noise environment of wayside communities resulting from all noise sources other than train pass-bys, are 69.9 dBA for the #5 route, and 68.9 dBA for the "D" route. $L_{dn}$(Ambient) levels range from 61 to 75 dBA for both routes combined.

### G.4.4 Relative $L_{dn}$

The Relative $L_{dn}$ is the amount by which the $L_{dn}$ (from all noise sources) differs from the $L_{dn}$(Ambient). It reflects both the $L_{dn}$(Trains) pattern shown in Figure G-16 and the $L_{dn}$(Ambient) distribution discussed above.

Figure G-17 illustrates the percent residential miles by Relative $L_{dn}$ level for the #5 and "D" routes. For both routes combined, the Relative $L_{dn}$ levels range from two to 19 dBA, with a mean level of seven dBA. The Relative $L_{dn}$ ranges and means for the #5 and "D" routes are as follows: 2 to 16 dBA, 5.0 dBA; and 2 to 19 dBA, 8.2 dBA, respectively.

Low Relative $L_{dn}$ levels (two to five dBA), experienced by nearly 42 percent of the residential wayside, are found primarily in communities adjacent to open-cut track. Generally, in these areas medium $L_{dn}$(Ambient) levels (61 to 70 dBA) combine with medium $L_{dn}$(Trains) levels, or high ambient levels (71 to 80 dBA) combine with high trains levels.

Relative $L_{dn}$ levels of six to ten dBA are recorded in approximately 50 percent of the residential areas. Although these levels can be found adjacent to all three types of track, nearly 70 percent of the mileage which experiences these Relative $L_{dn}$ levels is adjacent to grade track. In these communities,

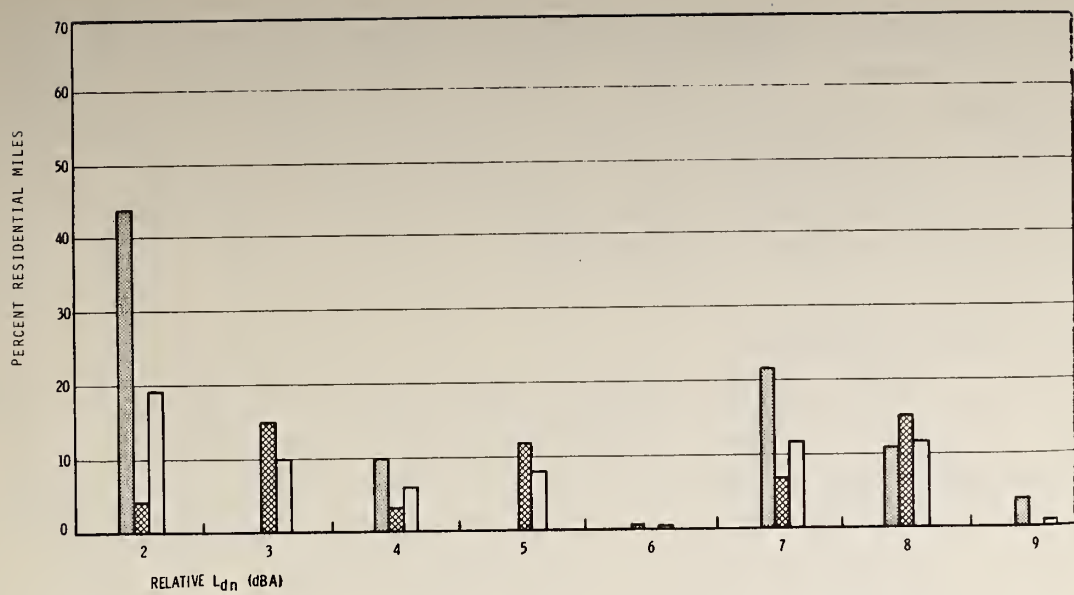



FIGURE G-17A IND-D AND IRT-#5, DISTRIBUTION OF WAYSIDE RELATIVE $L_{dn}$

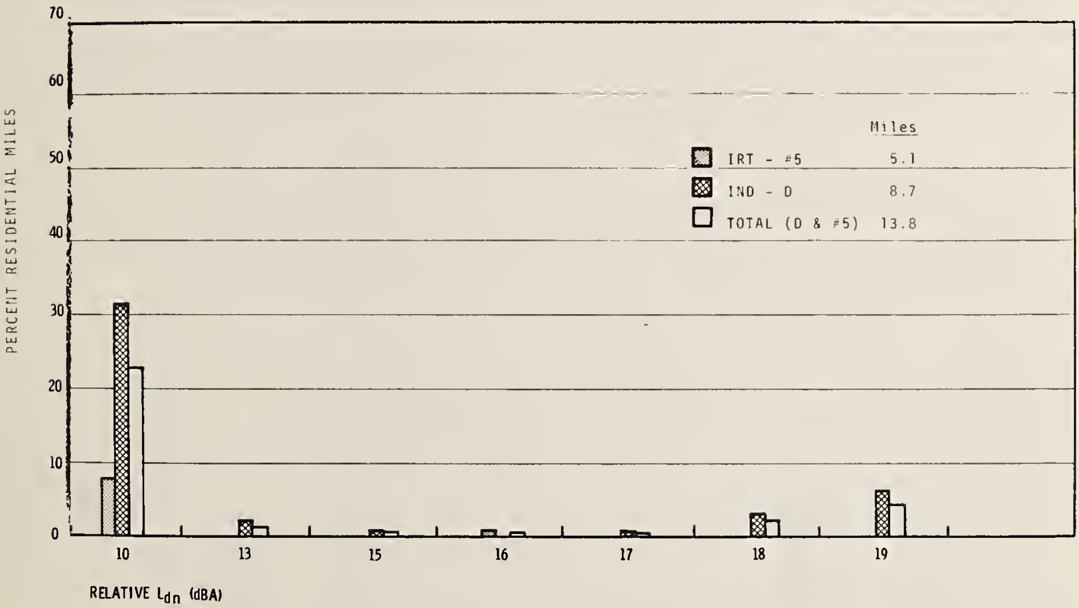



FIGURE G-17B IND-D AND IRT-#5, DISTRIBUTION OF WAYSIDE RELATIVE $L_{dn}$

medium $L_{dn}$(Ambient) levels are found in combination with high $L_{dn}$(Trains) levels. Only eight percent of the residential mileage experiences Relative $L_{dn}$ levels greater than ten dBA. The majority of these residential areas (83 percent) are adjacent to elevated steel track, where very high $L_{dn}$(Trains) levels (88 and 89 dBA) are recorded.

### G.4.5 Wayside Exposure

The total population residing within the 60-m (200-ft) corridor along aboveground segments of the #5 and "D" routes is estimated to be 22,400. Nearly two-thirds of this total populate the wayside communities adjacent to the "D" route, which includes both greater residential mileage and higher community densities.

The distribution of residential population against Relative $L_{dn}$ is illustrated in Figure G-18. The majority of the people are exposed to levels of six to ten dBA (approximately 52 percent), and less than ten percent of the population experiences Relative $L_{dn}$ levels greater than ten dBA. The remainder lives in communities where low Relative $L_{dn}$ levels (two to five dBA) are recorded.

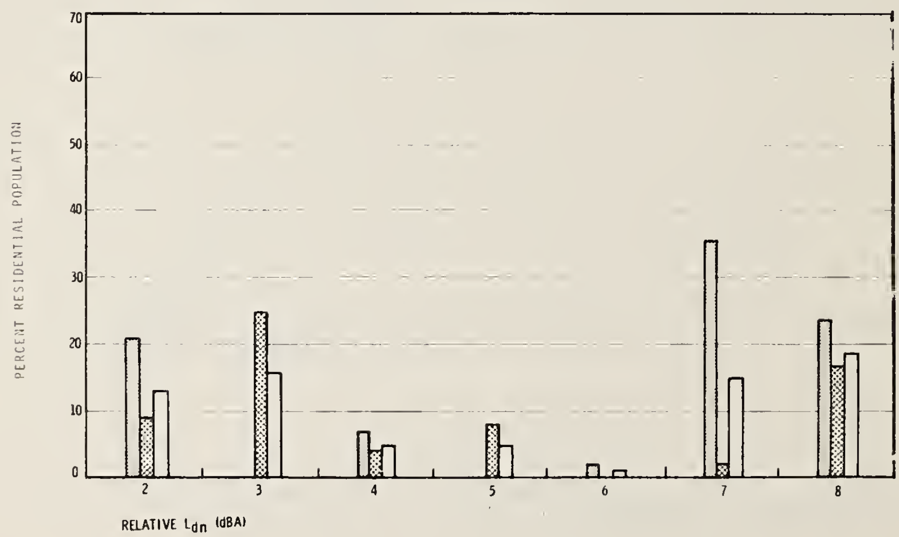



FIGURE G-18A IND-D AND IRT-#5, WAYSIDE NOISE EXPOSURE

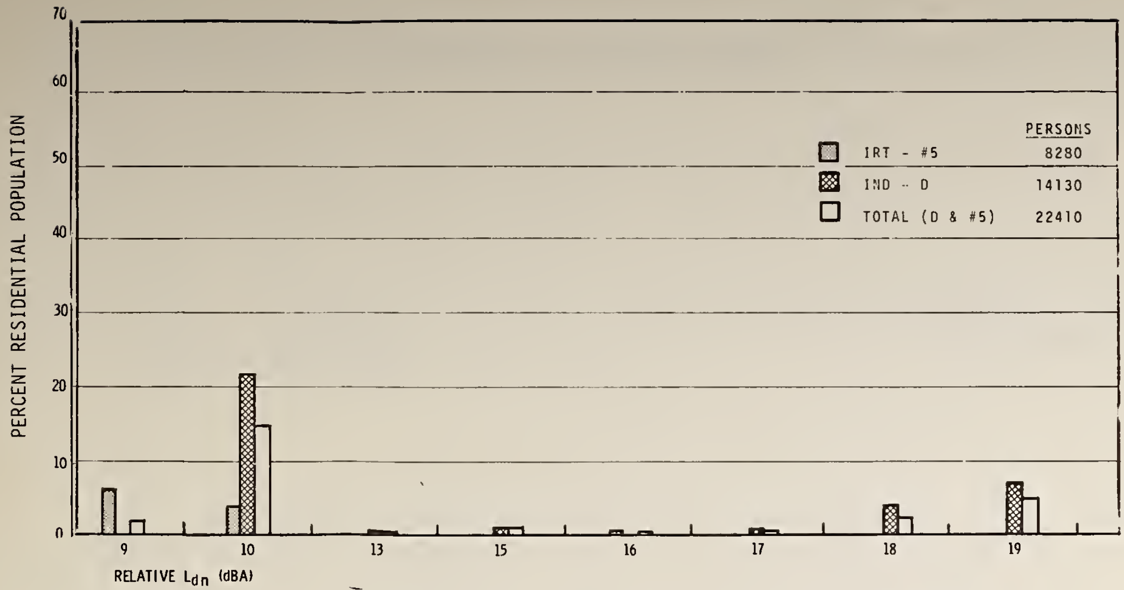



FIGURE G-18B IND-D AND IRT-#5, WAYSIDE NOISE EXPOSURE

## G.4.6 Comparison of Wayside $L_A$(Max) at 50 Feet with APTA Goals

Figures G-19 and G-20 show the distributions of $L_A$(Max) for the NYCTA and SIRT systems and the two representatives routes at 15m (50 ft), relative to the APTA goals for residential and non-residential wayside areas abutting the rail right-of-way.

Examining the NYCTA and SIRT systems, one finds that the majority (58 percent) of the residential mileage is exposed to levels greater than 15 dBA above the APTA goals, with the remaining mileage within ten dBA at the established APTA levels. For the non-residential case, approximately 9 percent of the mileage is below the goals, with an additional 35 percent within five dBA. The majority of the non-residential wayside areas (56 percent) are exposed to $L_A$(Max) levels more than ten dBA greater than the APTA level.

The wayside areas adjacent to the #5 and "D" routes combined experience $L_A$(Max) levels as much as 27 dBA higher than the APTA levels. Eighteen percent of the residential mileage is exposed to levels greater than 15 dBA above the established goals. However, the majority (51 percent) of the residential areas are

within ten dBA of APTA's goals. Of the remaining mileage, 33 percent is between ten and 15 dBA of the APTA level and 20 percent is in excess of 15 dBA.

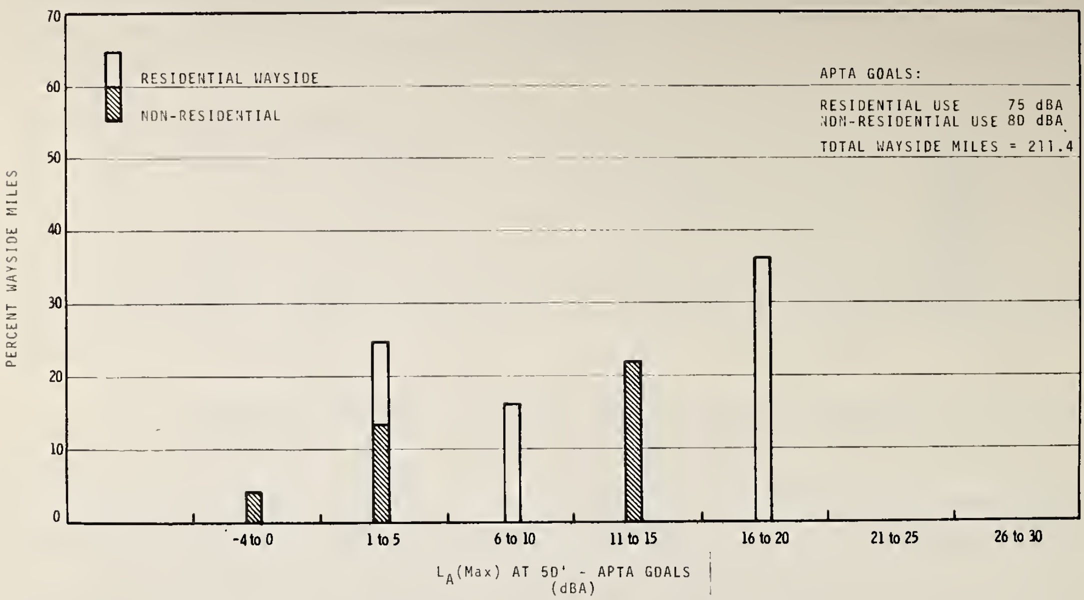



FIGURE G-19 NYCTA SYSTEM, WAYSIDE NOISE GUIDELINE COMPARISON

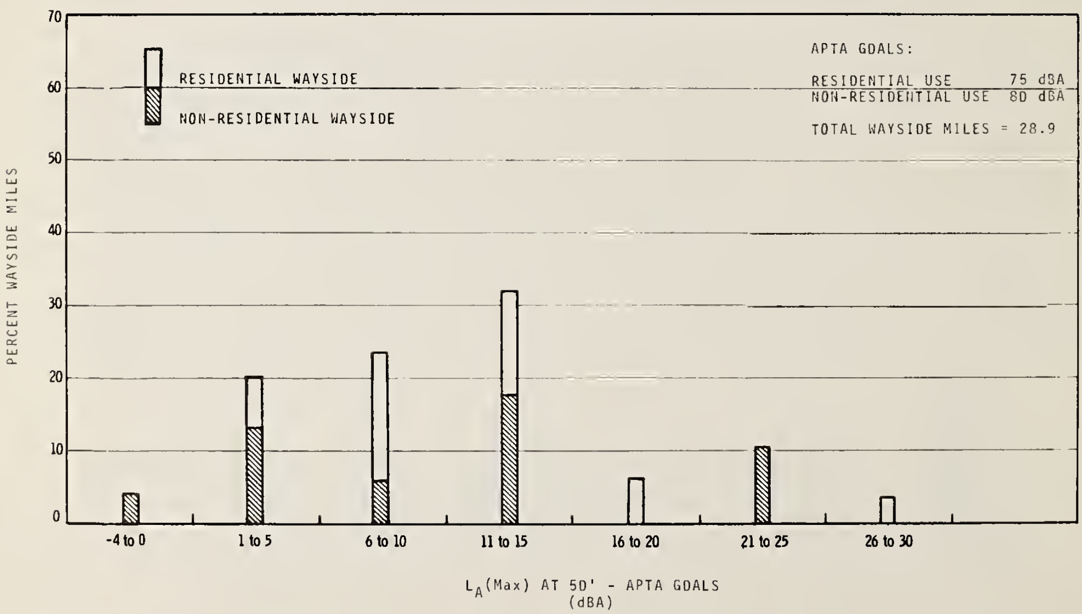



FIGURE G-20 IND-D AND IRT-#5, WAYSIDE NOISE GUIDELINE COMPARISON

# APPENDIX H - IN-CAR NOISE

The in-car noise environment for each rapid transit system has been characterized in two ways: first, by maximum A-weighted noise levels, $L_A$(Max), measured in the transit cars between stations during normal service runs; and second, by the equivalent sound level, $L_{eq}$ (usually derived from the $L_A$(Max)) experienced by a rider on an inter-station link.

## H.1 $L_A$(Max)

Frequency distributions showing the percentage of route-miles (as distinct from track-miles) versus $L_A$(Max) were compiled for each system. All data was gathered by direct measurement of in-car noise. For the transit property noise assessments, in-car sound level measurements were taken continuously for a full round trip, in the center of a sparsely filled transit car, with the microphone approximately 1.2 m (4 ft) above the floor. The maximum sound level was obtained from chart recordings of the history of the in-car noise. Essentially, the highest plateau level reached for each inter-station segment was used to characterize that entire route distance when compiling the frequency distributions.

## H.2 $L_{eq}$

The equivalent sound level between two stations can be estimated in the following way, assuming the time history is symmetrical about the midpoint of travel:

$$L_{eq} = 10 \log_{10} \left[ \frac{2}{T} \cdot \int_0^{T/2} 10^{(L_A/10)} \, dt \right] \qquad \text{(H.1)}$$

$L_A$ is the continuous sound level as a function of time. T is the travel time between stations. By using the $L_A$(Max) data from the

individual rapid transit systems and making some assumptions about the time history of sound level between any two stations, one can make an estimate of $L_A$.

It is assumed that time histories, generally, take two extreme forms. They can be rectangular, in which case the in-car noise level reaches a maximum immediately upon departure from the station and maintains that level until the transit car enters the following station. For this time history, $L_A$ is constant over the interval, so that $L_{eq} = L_A(\mathrm{Max})$. Alternatively, the time history can take a triangular form, where the maximum value is reached at the midpoint of travel (T/2). Sample in-car noise time histories between stations from various systems indicate that there is a maximum difference of 20 dBA between the lowest sound level between stations and the peak level. Using this 20 dBA difference, one can estimate $L_A$ for half the travel time as follows:

$$L_A = \frac{20t}{T/2} + (L_A(\mathrm{Max}) - 20). \qquad \text{(H.2)}$$

Substituting this expression for $L_A$ into equation H.1, one finds that $L_{eq} = L_A(\mathrm{Max}) - 6.67$.

Given the rectangular time history extreme $\left[L_{eq} = L_A(\mathrm{Max})\right]$ and the triangular time history extreme $\left[L_{eq} = L_A(\mathrm{Max}) - 6.67\right]$, one can make an average estimate of the $L_{eq}$ between stations. Using the energy average of the two levels, one determines the average $L_{eq}$ estimate between stations to be

$$L_{eq} = L_A(\mathrm{Max}) - 2.2 \text{ dBA}. \qquad \text{(H.3)}$$

## H.3 NOISE EXPOSURE

The derivation of $L_{eq}$ is the basis for the methods used here in describing the level of noise exposure of transit vehicle riders. The amount of time which riders are exposed to ranges of noise level along a route is the next consideration. Most transit

properties do not maintain records of numbers of riders versus their two-way work trip time on specific routes. It is difficult, consequently, to give a precise description of the noise exposure for each transit system. A national survey of ridership patterns for two-way work trips was taken in 1963 and is used in this report as an approximation of rider trip times on all the routes studied, regardless of length (See Figure 2-8).

For each trip time, it is assumed that the trip is distributed uniformly over the entire route. In other words, it is assumed that the length of exposure to the varying inter-station equivalent sound levels along the route is distributed in the same way that route-miles are distributed with equivalent sound levels along the route. Thus, if 20 percent of the route-mileage consists of inter-station track for which in-car equivalent noise levels between 76 and 80 dBA have been calculated, then 20 percent of x minutes will be considered the amount of time a person on an x-minute two-way work trip is exposed to levels between 76 and 80 dBA. Obviously, the percentage of actual exposure times to varying equivalent levels for groups of riders with different trip times cannot be the same, if the travel speed along the route is relatively constant for patrons. The need for this assumption becomes clear, however, when it is realized that the point of arrival to point of departure varies even within the same trip-time class. This is a best guess at the likelihood of patron exposure to certain ranges of inter-station equivalent sound levels.

A route description of noise exposure provides both an average noise level, $L_{eq}(R)$, along an entire route based on inter-station $L_{eq}$ values, and an estimate of the length of exposure to this average level. Since all trips are assumed to be distributed along the route as mileage is distributed, the route mileage can be used as a weighting factor to determine $L_{eq}(R)$. $L_{eq}(R)$ becomes:

$$L_{eq}(R) = \frac{1}{L_R} \sum_i L_{eq_i} \; L_i \qquad \text{(H.4)}$$

where $L_R$ is the total route distance, $L_{eqi}$ is the $L_{eq}$ for inter-station segment i, and $L_i$ is the length of the same inter-station segment. The people versus trip time national survey distribution gives the percentages of ridership and the length of exposure time to this average level of noise along a route.

The route equivalent level determined in this manner is consistent with measured values of route equivalent level. The maximum difference between evaluated and measured $L_{eq}(R)$ is 4.5 dBA, which can be attributed to the procedure used to determine the inter-station $L_{eq}$. For the route where this descrepancy exists, the distance between stations are relatively short. .76 km (0.47 mi) and the train speeds are as high as 48 km/h (30 mph), resulting generally in triangular time histories for in-car noise. The model used for evaluating inter-station $L_{eq}$, averages the expected $L_{eq}$ in terms of $L_A$(Max), corresponding to a triangular time history and a flat (plateau) time history. A triangular time history will result in a value 4.5 dBA lower than the averaged value.

Some transit systems are comprised of multiple routes with significant differences in type of track and ridership. For such systems, inter-station $L_{eq}$ and population versus trip time at $L_{eq}(R)$ have been evaluated on the individual routes. The $L_{eq}(R)$ used in the ridership frequency distribution for the transit system as a whole is an average value of $L_{eq}(R)$ determined from the routes, weighted by population (so that the average is more an indication of an average experienced level than a physical average).

## H.4 PEOPLE-HOURS VS $L_{eq}$

The primary approach to noise exposure which has been used in this report is the people-hours versus $L_{eq}$ distributions.

Making use of route-miles versus $L_{eq}$ histograms, trip time distributions, and the uniformly distributed trip assumption, one can take the product of the number of transit riders associated with a particular trip time and the trip time itself, and distribute this uniformly over an entire route. After this is done for

all trip times, the resulting people-hours at each equivalent level are added together, giving a total value of people-hours for that level. With more detailed data on average trip times for each route or each transit system, not available for this analysis, a people versus $L_{eq}$ distribution can be determined from people-hours versus $L_{eq}$, which gives an estimate of the average number of people exposed to the varying equivalent sound levels along the route.

For multi-route transit systems, the results on each route have been aggregated to present people-hours versus $L_{eq}$ for the transit systems as a whole.

## APPENDIX I - STATION NOISE

Like in-car noise, station noise is characterized by the maximum A-weighted noise levels, $L_A$(Max), and the equivalent sound level, $L_{eq}$, experienced by the patron on the station platform. Station sound level measurements were taken in 30-minute samples, with the microphone midway along the station platform, 2 m (6 1/2 ft) from the edge and 1.6 m (5 1/4 ft) above the floor.

### I.1 $L_A$(Max)

Most of the data received on station noise in the rapid transit systems under study were presented in terms of maximum arrival and departure levels from the near and far tracks, although on one rapid transit system the stations tested were characterized by averaging the arrival and departure maxima. In all the transit systems studied, levels were used to characterize the remaining untested stations. These samples were selected on the basis of physical features (e.g., layout and type of track).

From the actual and inferred noise data, frequency distributions indicating the percentage of stations versus average arrival-departure $L_A$(Max) were compiled for each system and route.

### I.2 $L_{eq}$

The equivalent station noise level depends on the time history of noise in a station over a specified time period. In the cases where $L_{eq}$ was directly measured, the time period of the measurement was 30 minutes.

Generally, the primary contributors to the station $L_{eq}$ are the entering and departing transit cars. Occasionally a public address system, an express train pass-through, or sources of noise other than those related to urban rail transit introduce levels

of noise which are significant components of $L_{eq}$. Where such sigularities do not occur, the following relationship characterizes the equivalent sound level over a 30-minute period:

$$L_{eq} = 10 \text{ Log} \left[ \left[ 10^{\overline{L_A(Max)\ NARR/10}} + 10^{\overline{L_A(Max)NDEP/10}} \right] \cdot \frac{N_N t_N}{1800} + \left[ 10^{\overline{L_A(Max)FARR/10}} + 10^{\overline{L_A(Max)FDEP/10}} \right] \frac{N_F t_F}{1800} \right] \quad (I.1)$$

$\overline{L_A(Max)NARR}$, $\overline{L_A(Max)NDEP}$, $\overline{L_A(Max)FARR}$, $\overline{L_A(Max)FDEP}$ are the arithmetically averaged track arrival and departure maximum noise levels, and the far track arrival and departure maximum noise levels, respectively. $N_N$ and $N_F$ are the number of near and far-track trains passing by in the 30-minute period. Finally, $t_N$ and $t_F$ are the time intervals during which the sound level is within 5 dBA of $L_A$(Max) on the near and far track for entering or departing time histories (as determined from strip chart recordings of time histories).* Applying this relationship to data obtained in 30 stations on various rapid transit systems where $L_{eq}$ was measured directly, one can establish that the difference between measured and calculated $L_{eq}$ is not significant at a level of confidence $\alpha = 0.05$ (See Figure I-1).

Actual $L_{eq}$ values, when available, were taken at selected stations on a system and used to estimate the $L_{eq}$ levels for untested stations on the system. In other systems where only $L_A$(Max) data exists for near-track arrivals, i.e., $\overline{L_A(Max)\ NARR}$, at selected stations, these levels were used as a basis for estimating near and far-track arrival and departure levels for all stations on the system. Equation I.1 was then used to estimate the station $L_{eq}$.

*It is assumed that both near-track and far-track entering and departing time histories have the same 5 dBA down time intervals.

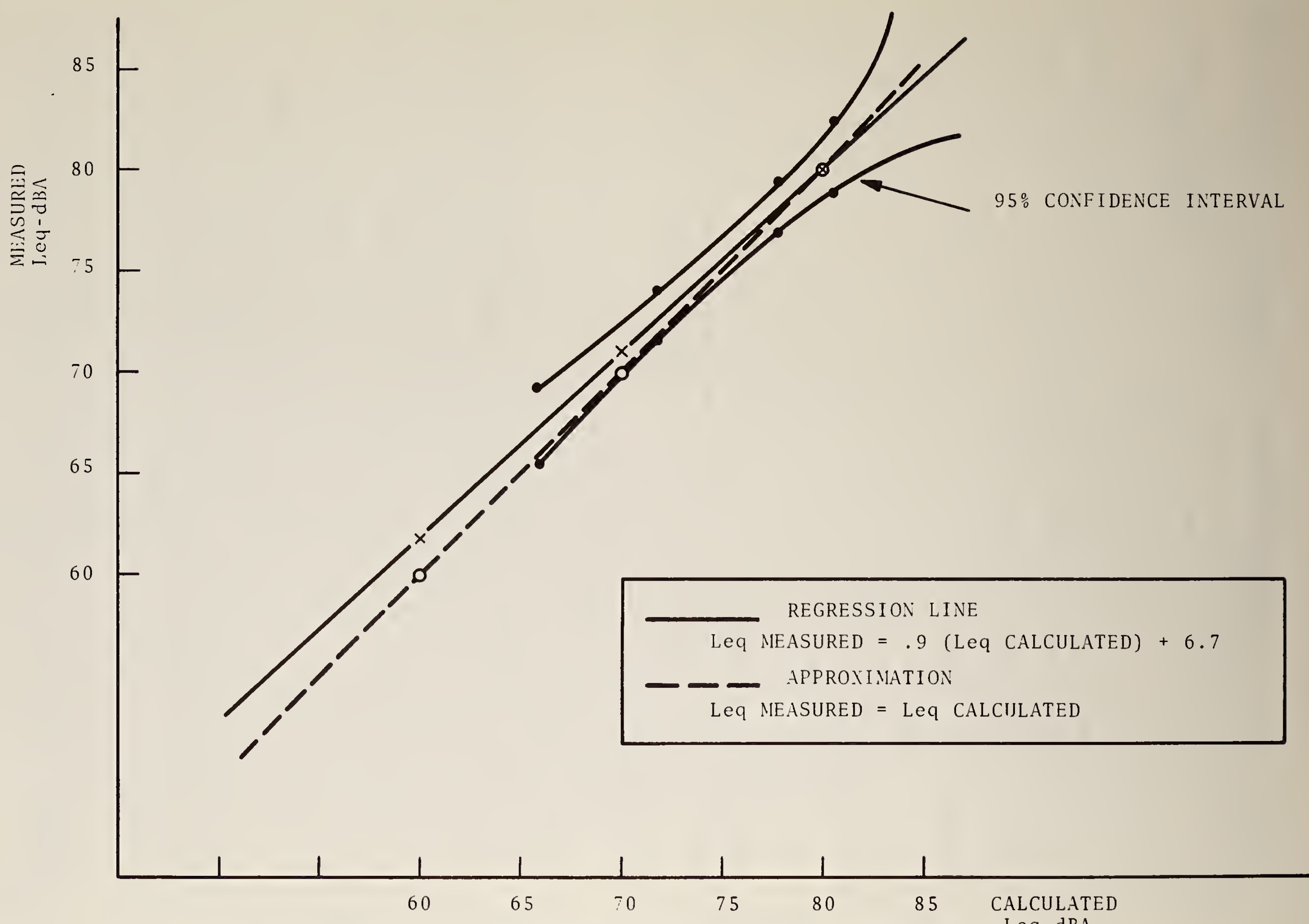



FIGURE I-1 SIGNIFICANCE OF CALCULATED STATION Leq

Linear regression techniques were used to evaluate $\overline{L_A(\text{Max})\ \text{NDEP}}$, $\overline{L_A(\text{Max})\ \text{FARR}}$ and $\overline{L_A(\text{Max})\ \text{FDEP}}$ in terms of $\overline{L_A(\text{Max})\ \text{NARR}}$. The correlation coefficients between these variables and $\overline{L_A(\text{Max})\ \text{NARR}}$ were as follows (using a 30-station sample): 0.86, 0.94, and 0.90, respectively. When the stations were separated by type of track, it was found that in subway and steel elevated stations the relationships were consistent with the coefficients shown, but that among the at-grade stations there was as much as a 30 percent deviation in the correlation coefficient between $\overline{L_A(\text{Max})\ \text{FDEP}}$ and $\overline{L_A(\text{Max})\ \text{NARR}}$. Transportation noise researchers at the Polytechnic Institute of New York have also considered the problem of predicting the single event departure level of one type of transit car in a station from the arrival of the same type of car in the same station; they found that the correlation was not significant among most car types.* In the National Assessment report, stations were not statistically eliminated in order to study the relationship between type of car and noise levels; instead, a less detailed picture of station noise was given which allows comparison between average noise levels.

## I.3 NOISE EXPOSURE

The transit properties have provided information concerning the number of transit patrons expected at each station. Using this data, one can compile frequency distributions of patronage versus station $L_{eq}$ levels. It would be expected that the patron waits on the station platform (or experiences the $L_{eq}$ value) for approximately one half the average headway time of the route or system. If the headway times are uniform throughout the peak patronage period, then the $L_{eq}$ value (based on 30 minutes during the peak hours) is a reasonable estimate of $L_{eq}$ for any period of exposure on the order of a headway time, and the frequency distributions are reasonable estimates of the number of patrons exposed to those levels.

*W. McShane, S. Slutsky, and M.F. Huss, "Noise Assessment of the New York City Transit Rail Rapid Transit System," UMTA MA-06-0025-79-7.

## APPENDIX J - WAYSIDE NOISE

### 3.1 INTRODUCTION

To assess the impact of train pass-by noise on the wayside community, the magnitude and duration of pass-by noise and the type of community experiencing this noise must be considered. In this report, the average maximum pass-by noise levels, $L_A$(Max), as measured and reported by earlier researchers, have been extrapolated to characterize the pass-by noise levels at all wayside locations. From these maximum noise levels, a cumulative measure of community sound levels, including pass-by noise, $L_{dn}$, has been derived and compared with the estimated ambient noise which would exist in the community if trains were not present, to give a relative noise level. The types of land use in the wayside community have been classified as either residential or non-residential, and an estimate has been made of the size of the population in residential wayside areas.

The process of wayside sound level, land use, and demographic data collection and analysis summarized in Figure J-1. Characteristics of the wayside exposure corridor are discussed in Section J-2. The derivation of community ambient day-night equivalent sound levels is explained in Section J-3. Section J-4 outlines the algorithm used in deriving the day-night equivalent sound level resulting from train pass-bys. Finally, Section J-5 discusses the derivation and significance of relative $L_{dn}$ levels.

### J.2 CHARACTERISTICS OF THE WAYSIDE CORRIDOR

#### J.2.1 Dimensions of the Wayside Corridor

Taking the 60-m (200-ft) distance from the track center-line as the outer limit of the wayside community, and 15 m (50 ft) as the inner limit, one established a narrow corridor, 45 m (150 ft) wide, along each side of the track. This corridor defines the approximate limits of the wayside community most affected by train pass-by noise.

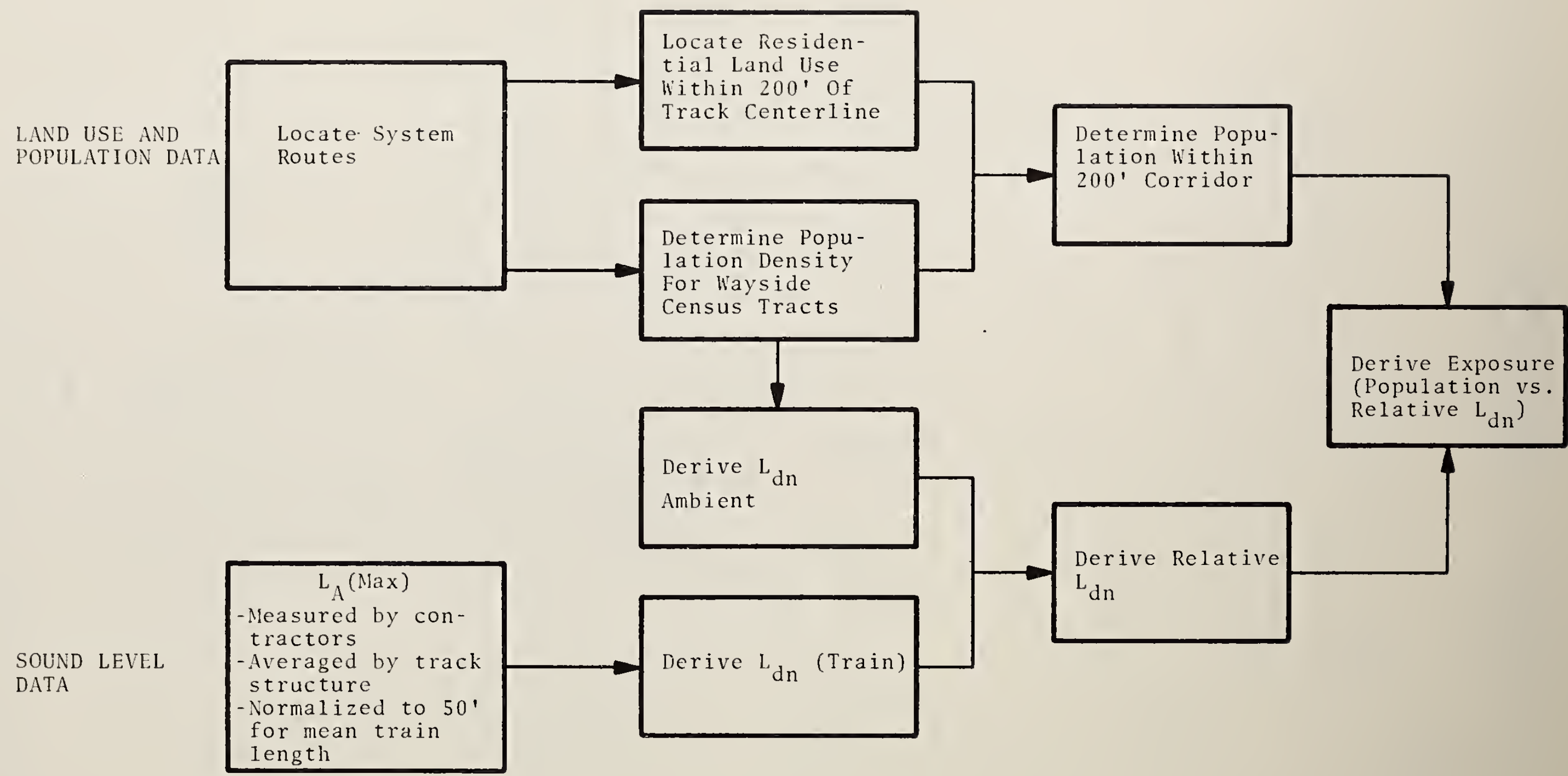



FIGURE J-1 WAYSIDE SOUND LEVEL, LAND USE, AND DEMOGRAPHIC DATA ANALYSIS PROCEDURE

### J.2.2 Land Use Determination

In terms of community exposure, the emphasis in this study has been on identifying residential wayside areas. The remainder of the wayside community has been classified as non-residential, without classification according to type. It would be difficult to determine the number of people at non-residential areas or the length of time each person spends at a non-residential location. The interior or site-specific ambient noise levels for non-residential areas would also be expected to be more ambiguous than those for residential areas.

Residential locations were obtained from a variety of mapped sources, with a wide range of variation with regard to classification sensitivity, scale of presentation, and level of detail in categorization. Typical sources included municipal and regional planning agencies, Federal and university mapping studies, and private organizations involved in urban land use mapping (See references).

For the wayside analysis, if any part of the 60-m (200-ft) corridor was in an area designated as predominantly residential, this part of the corridor was designated as residential wayside.

Only wayside areas along aboveground track were considered to be significantly affected by train pass-by noise, as noise levels around subway vent shafts were recorded as being nominal.

### J.2.3 Determination of Wayside Population Density

To estimate the size of the population residing within the 200-foot corridor, (beyond the 15-m (50-ft) inner limit) and the ambient community day-night equivalent sound levels, as described in Section J.3, a measure of population density was needed. The national data available were gross density figures for census tracts.

Residential density levels were obtained from U.S. Census Urban Atlases, and the National Planning Data Corporation. The assumption was made that densities within census tracts were uniform. Analysis of sections of MBTA wayside residential densities

indicates that, for these areas, densities of census blocks near the track tend to be higher than densities of the larger surrounding area. This pattern appears to hold true over a wide range of density levels and may be due to location of higher density, lower cost housing near the rail right-of-way. Using entire tract density levels would, therefore, tend to underestimate the actual population near the right of way.

The use of gross densities rather than net residential densities may also result in an underestimation of wayside population, as only those wayside areas classified as residential are weighted by population density to determine population. This was considered more accurate, however, than weighting the entire aboveground wayside by gross density; net residential densities were not available.

### J.2.4 Average Wayside Sound Levels

The arithmetic average of the maximum A-weighted sound levels resulting from all near-track pass-bys during a 30-minute sampling period is used to determine the wayside $L_A$(Max) for a particular wayside location. Wayside measurements were taken on the open street or sidewalk, 15 m (50 ft) from the track center-line, at a height of 1.6 m (5 1/4 ft) above ground level. One can extrapolate wayside $L_A$(Max) levels for locations where sound Extrapolations were derived based on the type of track structure, type of rail. and where given, train speed for each line of a transit system. For example. one typical noise level was used to characterize the wayside along all elevated, jointed track on the northern section of the SEPTA Market-Frankford Line (See Figure B-2.) Given an average $L_A$(Max) for pass-by levels at 15 m (50 ft), one then has to determine the average pass-by level for the population within this 60 m (200-ft) wide corridor. Stated in terms of the sound level at 15 m (50 ft) from the track center-line, the problem becomes:

What is the shift in sound level between the measured level of community noise 15 m (50 ft), $L_A^{(50)}$ and the average sound level for the population living between 15 m (50 ft) and 60 m (200 ft) from the near-track center-line, $\overline{L_A}$?

Assumptions:

1. The population is uniformly distributed between 50 and 100 feet.

2. The line source model is used to characterize the propagation of sound from long trains for the distances measured:

$$L_A(r) = L_A^{50} - 10 \log \frac{r}{r_o} \tag{J-1}$$

where

$r_o$ = 15 m (50 ft)

$$\overline{L_A} = \frac{\int L_A(r) \cdot r \cdot dL_A(r)}{\int r dL_A(r)} \tag{J-2}$$

so that

$$\overline{L_A} = \frac{\int_{50}^{200} \left(L_A^{50} - 10 \log \frac{r}{50}\right) dr}{150} \tag{J-3}$$

$$\overline{L_A} = \frac{L_A^{50}(150) + 4[r\ln r - r]_{50}^{200} + 4 \cdot \ln(50) \cdot (150)}{150} \tag{J-4}$$

$\overline{L_A}(r) = L_A - 3.39$ dBA. This level of $\overline{L_A}$ is equal to the level of $L_A$ which corresponds to a distance of 33.3 m (109.1 ft) from the near track center-line.

## J.3 DERIVATION OF COMMUNITY AMBIENT NOISE ESTIMATES FROM POPULATION DENSITY

Ambient community noise levels were derived from information in the Bolt, Beranek and Newman (BBN) report, "Population Distribution of the United States as a Function of Outdoor Noise Level."

BBN conducted a survey of 100 urban sites in the United States to assess the noise levels in residential areas primarily exposed to noise from sources other than airports, freeways, or rail systems.

The A-weighted sound level was the measure used for defining the community noise levels. The results indicate that $L_{10}$, $L_{50}$, $L_{90}$ and $L_{dn}$ are all correlated at greater than 0.7, with log of the population density, $\rho$, in people/sq. mile. The regression line computed for the relationship between $L_{dn}$ and $\rho$ has the form:

$$L_{dn} = 9.00 \log_{10} \rho + 25.8 \text{ for } \rho > 1 \qquad \text{(J-5)}$$

Based on a hypothesis that community ambient noise is dependent on motor vehicle noise, and a series of assumptions about the relationship between motor vehicle noise and population density, BBN estimated that urban noise would vary as $10 \log_{10} \rho$. The predictive equation for $L_{dn}$ is as follows:

$$L_{dn} = 10 \log_{10} \rho + 22 \text{ for } \rho > 1 \qquad \text{(J-6)}$$

At the 0.05 level, the hypothesis that there is no difference between the two formulae cannot be rejected.

### Applications to the MBTA

In the case of the MBTA, field measurements were taken to determine the ambient community sound levels at the same locations used for train pass-by noise measurements. These measured community noise levels (without the presence of train noise) represent the average plateau sound level at the site. If this measured

average plateau sound level is assumed to approximate the equivalent sound level, $L_{eq}$, the ambient day-night sound level may be calculated using the following relationship:

$$L_{dn}(\text{Ambient}) = 10 \log \left[ \frac{\sum_{i=1}^{n} 10^{L_{eq}/10} \cdot \omega_i T_i}{24} \right] \qquad \text{(J-7)}$$

$\omega_i$ = time-of-day weighting factor

$\omega_i$ = 1 0700-2200

$\omega_i$ = 10 2200-0700

$T_i$ = time interval for $i^{th}$ period.

In applying the above relationship, one assumes further that the $L_{eq}$ for night hours ($L_N$) differs from the $L_{eq}$ for daytime ($L_D$) hours by a constant amount. Using field data for sites having a wide range of residential densities, one arrives at an average $L_D$-$L_N$ difference of eight dBA. (The quantity ($L_D$-$L_N$) appears unrelated to density level.*) In Figure J-2, $L_{dn}$ levels derived from these measured ambient noise levels are compared with community noise levels derived from the relationship with population densities previously described, based on the population densities of residential areas closest to the measurement location. In only two instances is there more than a 3 dBA difference between the two ambient noise levels.

The above similarity appears to be further confirmation of the validity of the derivation of ambient noise levels based on population densities, and the applicability of this derivation for wayside noise levels. With the BBN approach, it is possible to make a more complete description of the distribution of ambient noise levels in wayside communities than that provided by the field measurements, as population density information is available for all residential wayside areas.

*U.S. EPA, "Population Distribution of the U.S. as a Function of Outdoor Noise Level," prepared by Bolt, Beranek and Newman, Inc., PB 235 022, June 1974, p. 14 and Appendix D.

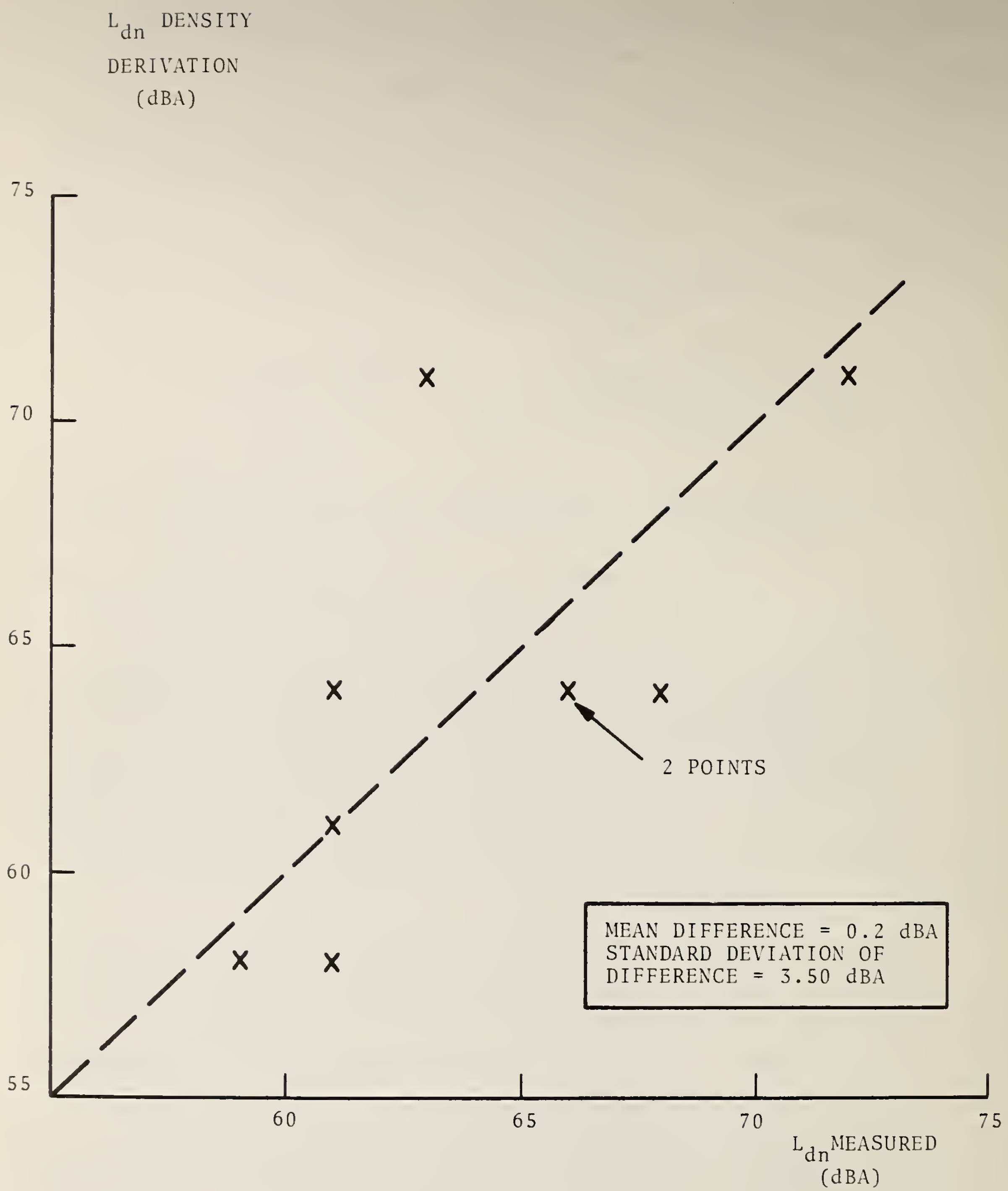



FIGURE J-2 AMBIENT WAYSIDE NOISE LEVEL COMPARISON

## J.4 DERIVATION OF DAY-NIGHT EQUIVALENT NOISE ENERGY LEVELS

The equivalent sound level, $L_{eq}$, and the day-night equivalent sound level, $L_{dn}$, are both measures which represent the cumulative effect of many isolated single sound events, such as train pass-bys, over a longer period of time. The $L_{eq}$ represents the equivalent steady noise level which, in a given period of time, would contain the same noise energy as the time-varying noise during the same period. $L_{dn}$ is the equivalent A-weighted sound level over a 24-hour period with a ten decibel penalty applied to the equivalent sound level for nightime hours, 10 P.M. to 7 A.M. As defined in this report, $L_{dn}$(Trains) is the day-night equivalent sound level resulting only from train pass-bys. $L_{dn}$(Trains) was generally not measured directly, but was derived using the following methods.

### J.4.1 Determination of $L_{dn}$ (Trains)

The data supplied by the original contractors are used to derive $L_{dn}$ (Trains) by taking advantage of an approach based on the single event noise exposure level, SENEL, for a train pass-by:

$$\text{SENEL} = L_A(\text{Max}) + 10 \log T. \qquad \text{(J-8)}$$

where T is the effective duration in seconds defined as follows:

$$T = \frac{nl}{v} \left[1 + 1.2 \left( \frac{d}{nl} \right)\right] \qquad \text{(J-9)}$$

and n, l, v, d represent the number of transit cars, the transit car length (m), the train speed (m/s), and the distance of the receiver from the trains (m), respectively. An $\text{SENEL}_T$ can be defined such that the noise exposure computed is that due to two pass-bys, one on the near track ($\text{SENEL}_{NT}$) and one on the far track ($\text{SENEL}_{FT}$):

$$\text{SENEL}_T = 10 \log \left[10^{\text{SENEL}_{NT}/10} + 10^{\text{SENEL}_{FT}/10}\right] \qquad \text{(J-10)}$$

so that $L_{dn}$ becomes

$$L_{dn}(\text{Trains}) = \text{SENEL}_T + 10 \log (N_D + 10N_N) - 49 \qquad \text{(J-11)}$$

where $N_D$ = number of pass-bys* from 0700-2200 hours

$N_N$ = number of pass-bys from 2200-0700 hours.

If the train length, speed or consist varies between day and night, $L_{dn}$ can be computed from:

$$L_{dn}(\text{Trains}) = 10 \log [N_D E_D + 10 N_N E_N] - 49 \qquad \text{(J-12)}$$

where $E_i = 10^{(\text{SENEL}_i/10)}$ $\qquad i = D,N$

$\text{SENEL}_D$ = daytime $\text{SENEL}_T$

$\text{SENEL}_N$ = nighttime $\text{SENEL}_T$.

### J.4.2 Determinants of $L_{dn}$(Trains) Levels

The effect on $L_{dn}$(Trains) levels of varying train speed and headway schedules, is illustrated in Figure J-3.

Based on the relationship that $L_A$(Max) is proportional to 30 log V (V = train speed), and T, the effective pass-by duration, is proportional to 1/V, Eq. (J-8) indicates that SENEL (and hence $L_{dn}$) will increase by 6 dB per doubling of speed.

Doubling the headway times reduces the number of pass-bys by 50 percent, and thus reduces the $L_{dn}$ (Trains) by 3 dBA, for a given train speed.

## J.5 RELATIVE $L_{dn}$

The measure of relative $L_{dn}$ represents the increase in equivalent day-night sound levels in a community resulting from the addition of train pass-by noise.

*On the near or far track, assuming the two are the same.

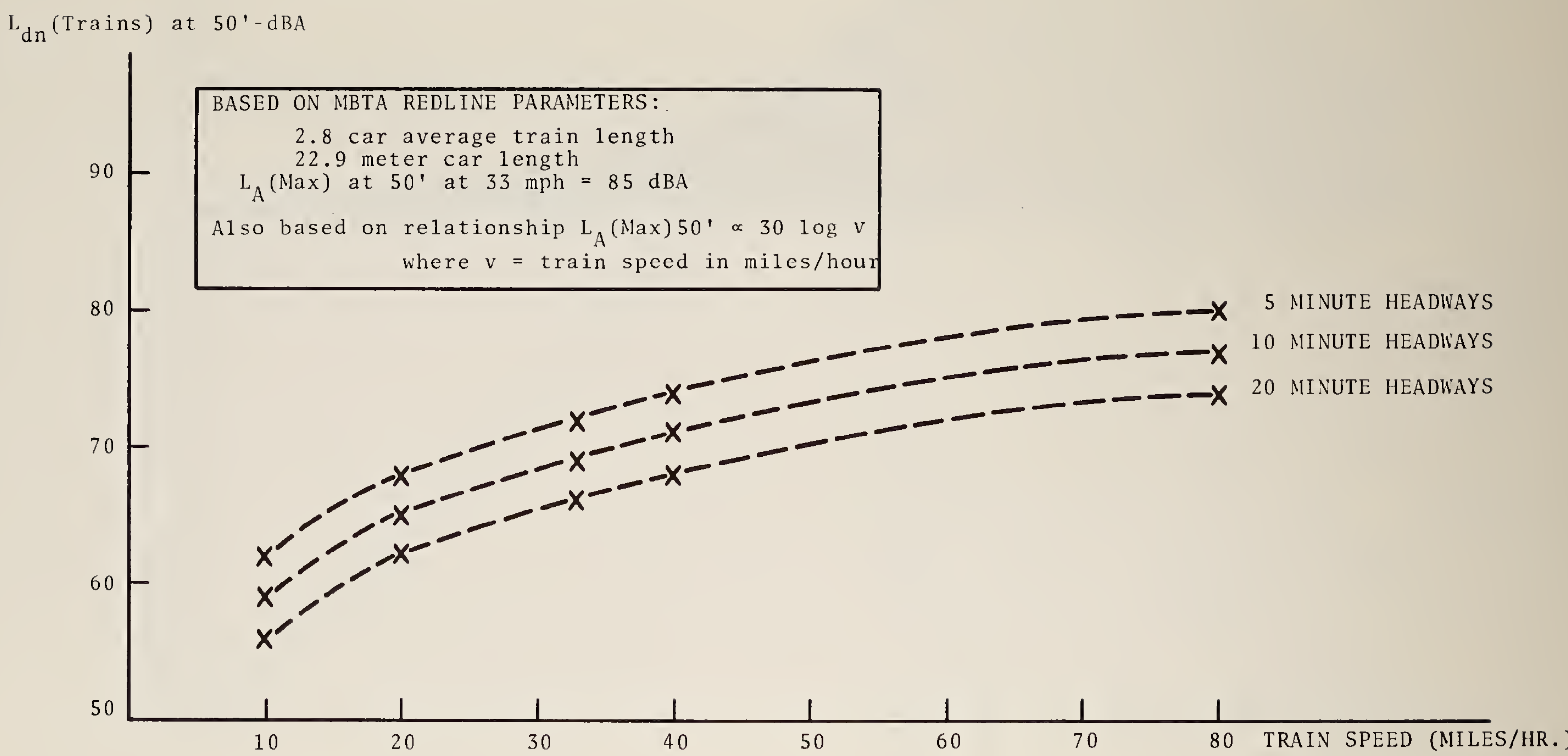



FIGURE J-3 RELATIONSHIP BETWEEN $L_{dn}$(TRAINS) AND TRAIN SPEED AND HEADWAY TIMES

$$\text{Relative } L_{dn} = L_{dn} - L_{dn}(\text{Ambient}) \qquad (J\text{-}13)$$

where $L_{dn}$ is the community day-night equivalent sound level resulting from all noise sources (i.e., $L_{dn} = L_{dn}$(Trains) + $L_{dn}$(Ambient), decibel sum). The relative $L_{dn}$ is the arithmetic difference between $L_{dn}$ and $L_{dn}$(Ambient). Figure J-4 illustrates the effect of adding various train pass-by sound levels, $L_{dn}$(Trains), (described in Section J-4) to a given community sound level which would exist without the presence of train pass-bys, $L_{dn}$(Ambient), described in Section J-3. When $L_{dn}$(Trains) is considerably less than $L_{dn}$(Ambient), the total $L_{dn}$, including train noise, is only slightly more than the $L_{dn}$(Ambient). Conversely, when the $L_{dn}$ (Trains) is much greater than the $L_{dn}$(Ambient), the combined $L_{dn}$ is approximately the same as the $L_{dn}$(Trains). When the $L_{dn}$(Trains) and $L_{dn}$(Ambient) are equal, the resulting combination of the two sound levels is three dBA more than either individually.

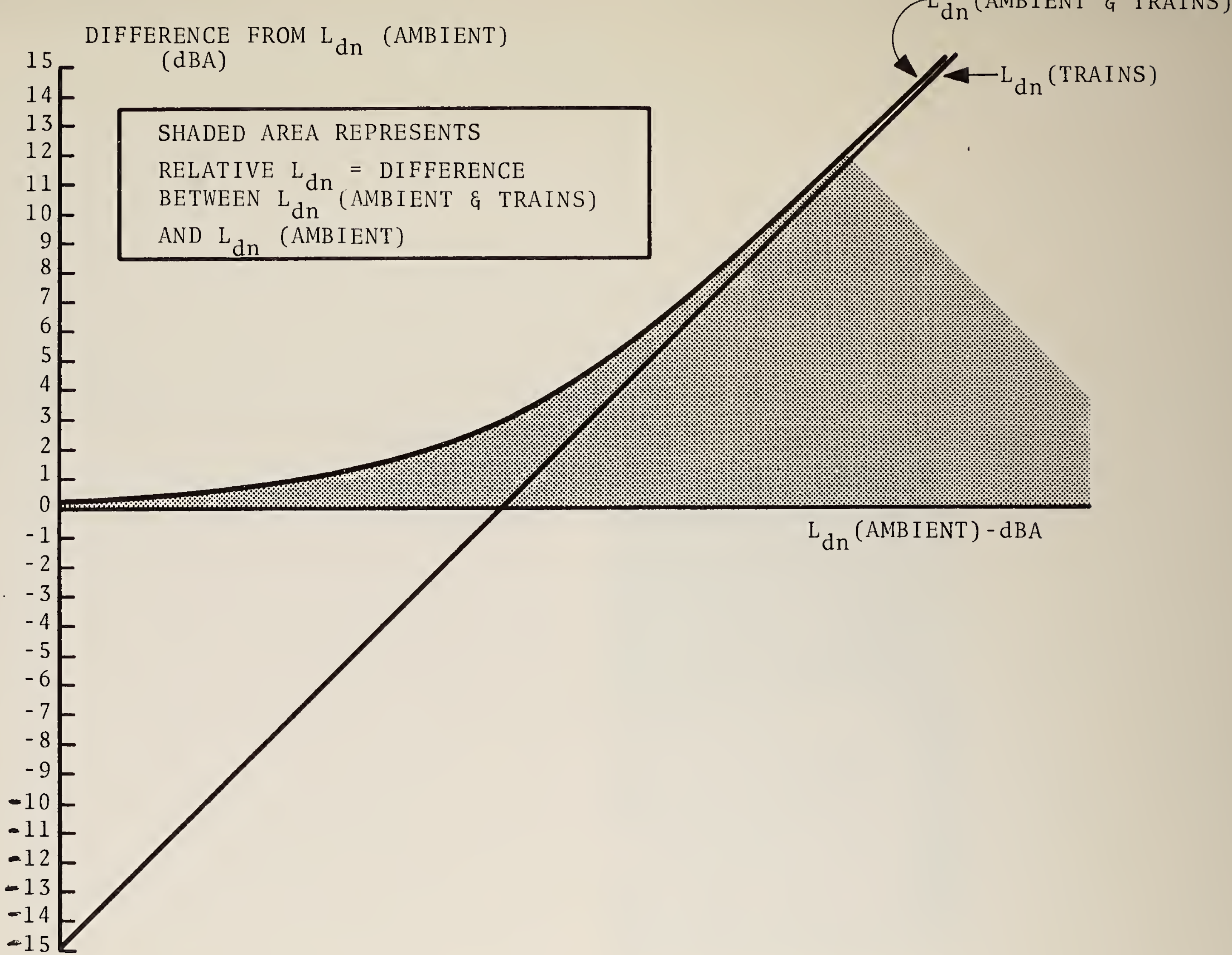



FIGURE J-4 ADDITIVE EFFECT OF VARIOUS TRAIN PASS-BY LEVELS TO A GIVEN AMBIENT SOUND LEVEL

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